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TECHNOLOGY REVIEW

SEPTEMBER 2001

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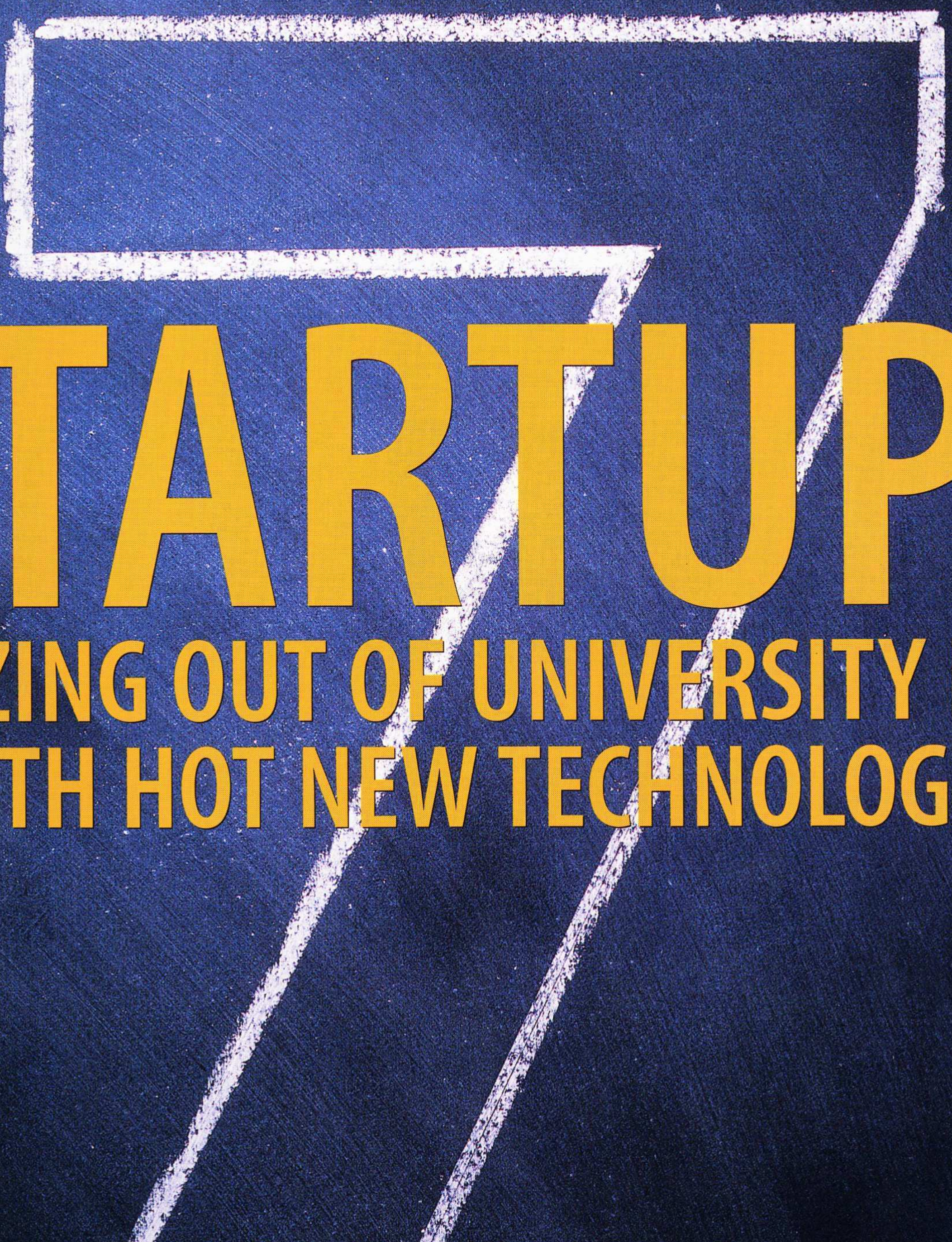

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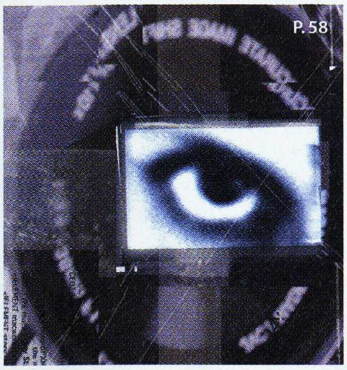

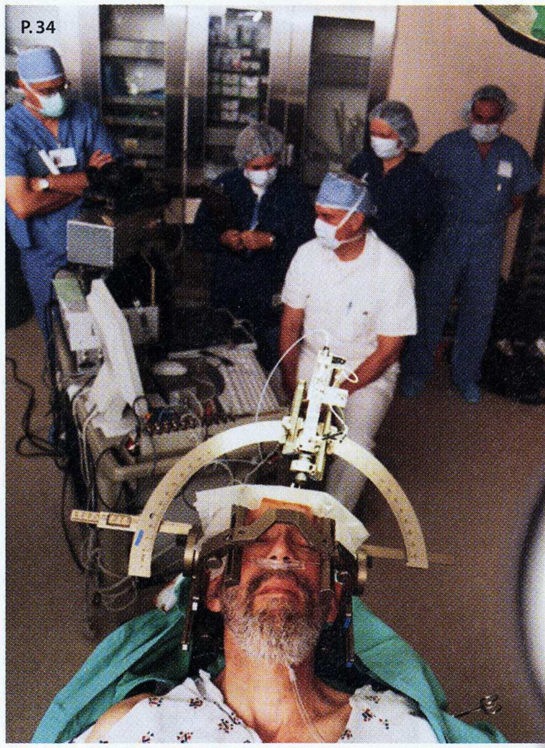

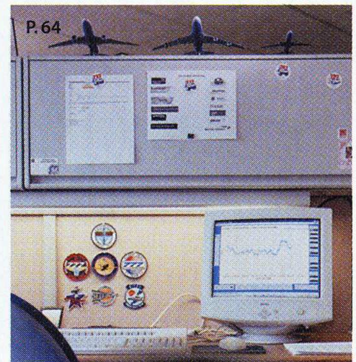

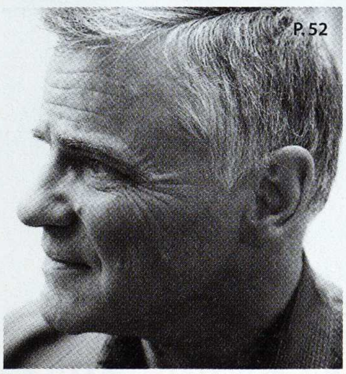

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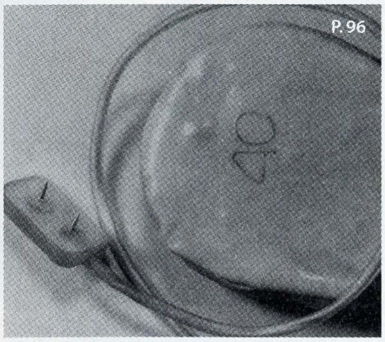

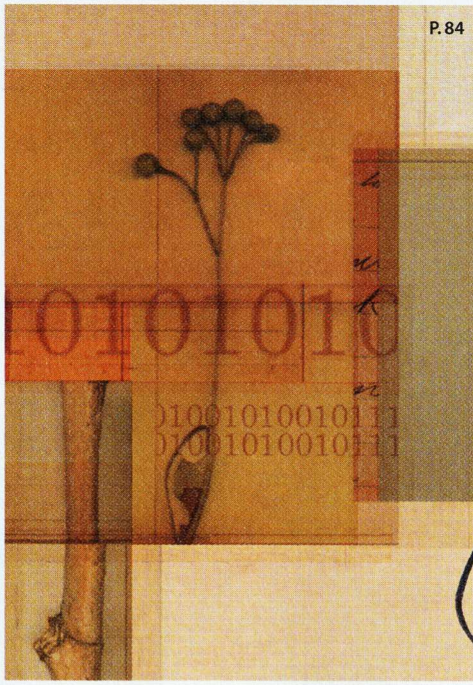

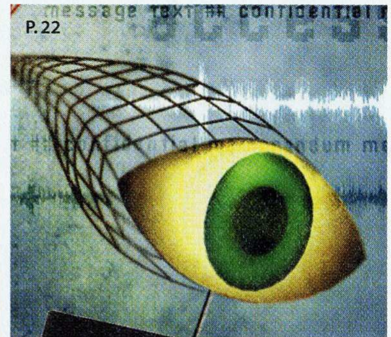

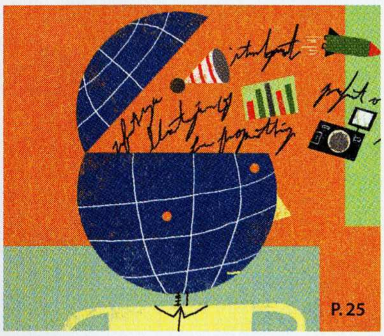

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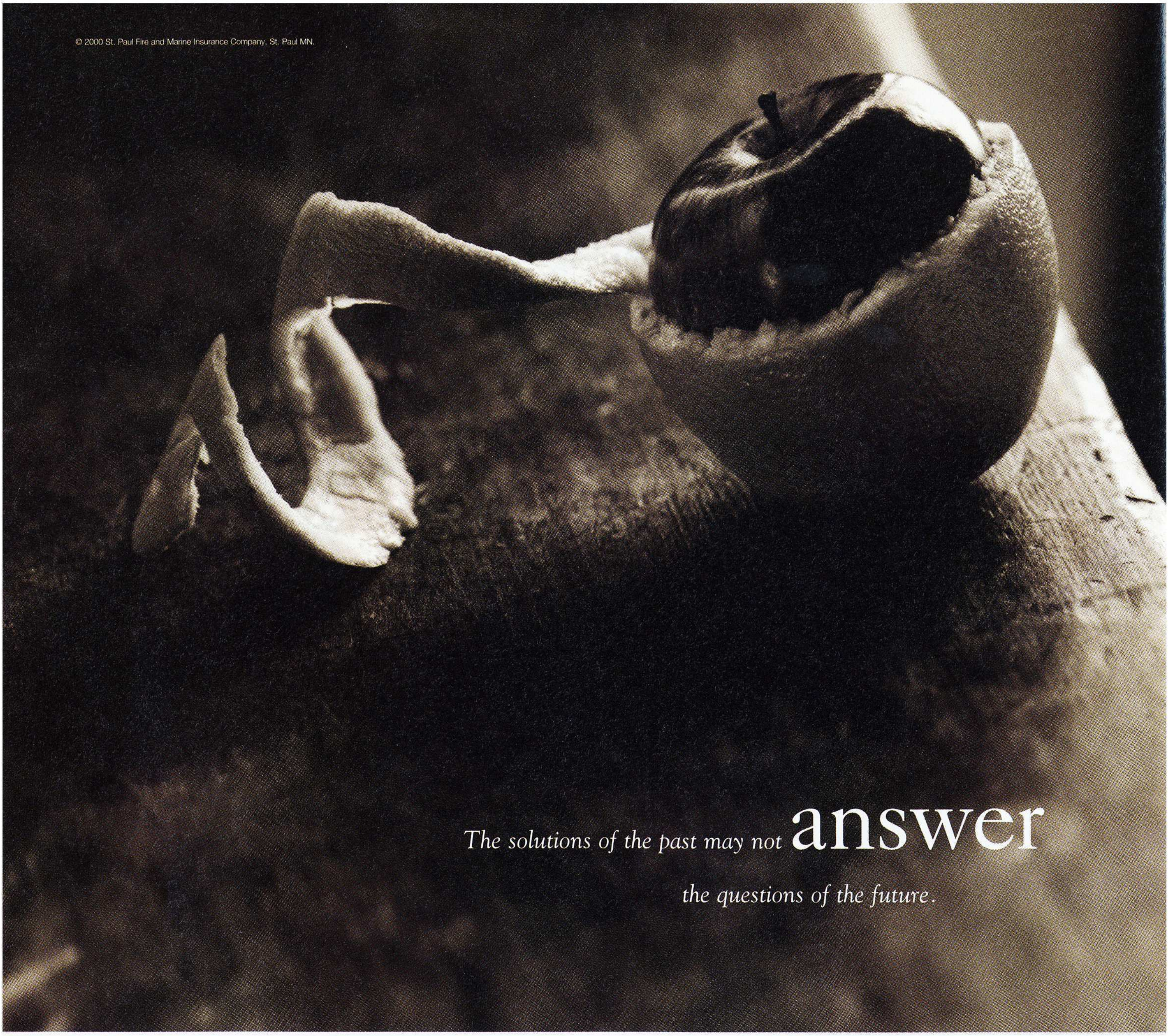
COLUMNS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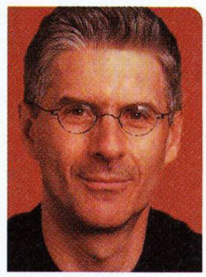
The solutions of the past may not answer
the questions of the future.

Creepy Functions

FUNCTION CREEP IS WHAT JOHN WOODWARD CALLS IT. WOODWARD is an ex-CIA man, now working for the Rand Corporation, who was one of Ivan Amato's sources for the story on ubiquitous surveillance that begins on page 58 of this issue. Woodward uses this colorful phrase to describe how Information Age surveillance and monitoring systems, built and bought for a benign use, can subtly be shifted to sinister purposes.

Consider one example of function creep. The Electoral Commission of Uganda has retained Viisage Technology to implement a face recognition system capable of enrolling 10 million voters in 60 days. The goal is to reduce voter registration fraud. But Woodward notes that the system might also be put to work fingering political opponents of the regime. And Uganda probably isn't the first country that springs to mind when someone says "due process" or "civil rights."



The central question raised by Amato's story is: Who will decide which functions of a dramatic new technology are acceptable and which are just too, well, creepy? As Amato's story and others that have recently appeared in *TR* suggest, we all need to think carefully about how new technologies are implemented and used. And after we've thought about it, we need to do something about it. If we don't, then the decisions will get made by those with deep pockets and deep vested interests. We need to wake up to these issues soon, because "the technology is developing at the speed of light, but the privacy laws to protect us are back in the Stone Age," as Barry Steinhardt, associate director of the American Civil Liberties Union, put it to Amato.

The same theme surfaces in another story in this issue, "Taming the Web," by Charles C. Mann *(p. 44)*. Mann takes on a myth, incubated in the hacker culture, that has now spread to the rest of the world: that the Internet is too big and too anarchic to be controlled. Mann outlines three arguments that have been advanced to support this view: (1) the Net is too international to be controlled, (2) the Net is too interconnected to control and (3) there are just too many hackers for control to be established. In a provocative article, Mann shows that two of these arguments are false and one is irrelevant. There is no doubt, he writes, that the Internet will be controlled. The only question is—by whom?

"Governments are going to set down rules," Internet-law specialist Justin Hughes at the University of California, Los Angeles, tells us in Mann's piece, "and if you spend all your time fighting the existence of rules, you won't have much chance to make sure the rules are good ones." Those who claim that the Internet is inherently resistant to control have taken themselves out of the process of formulating those rules. In their absence, others, such as corporations and government agencies, will be only too happy to step in.

As these two articles make clear, new technologies are raising critical questions of public policy that must be answered soon. Yet many of these developments are taking place outside the public view—because the technology seems arcane or because its impact hasn't been grasped by the public. By bringing the impact of emerging technologies into the spotlight, *Technology Review* intends to change all that. Cutting-edge technology is no longer an exotic realm where experts rule. It affects us all, and we all need to step up and take responsibility for how it's used.

—John Benditt

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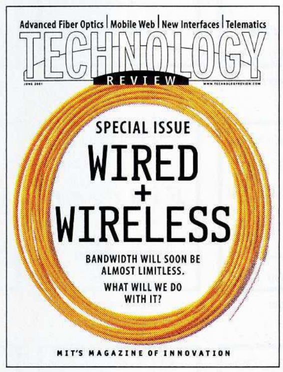
"When I typed my credit card with spaces, there was no warning. The vendor chastised me for being an idiot, then cleared the fields from the form!"

Facing Interfaces

SIMSON GARFINKEL IS CORRECT IN noting that most undergraduate computer programs do not teach interface design ("May the Best Interface Win!" *TR* June 2001). However, I question how much importance should be placed on "usability" in the university environment. The Oracle database that conveniently stores your shopping cart was developed because a great deal of work was done on data structures. The reason that the site finds a particular book out of tens of millions of others in three seconds rather than 30 seconds is that someone designed a better search algorithm. The usability of a Web site is meaningless if it takes five minutes for the computer to pull up your shopping cart because of an inefficient searching algorithm.

MARK KIM
Madison, WI



SIMSON GARFINKEL IS RIGHT ON TARGET about many e-commerce sites being hard to use. However, he fails to realize that there is an entire discipline dedicated toward doing exactly the kind of design that he begs for. It is called usability engineering. While not all computer or software engineering departments require courses in this area, here at Florida International University, our industrial engineering department has a master's-degree track in usability engineering, and we require all of our information systems engineering students to take at least one course in usability engineering. We also offer a course specifically in usability engineering for e-commerce. I can assure Mr. Garfinkel that we teach our students to do exactly what he asks: namely, to design the shopping cart, search and browsing functions to be easy to use, maximize download speeds and protect customers' privacy. We design systems that allow customers to type dashes in their credit-card numbers and *O*s for *0*s. Our graduates are earning positions with some of the leading e-commerce companies. It will just take us a little time to populate the entire industry.

MARC RESNICK
Director, Usability Engineering track
Florida International University
Miami, FL

WHILE UNIVERSITY COMPUTER science departments certainly share some of the blame for not educating their students in usability, there are other, equally important reasons for poor interfaces. One major culprit is the rapid software-development life cycle. Good user interfaces take time and care to build: they do not just happen. Many companies would rather focus on coding and consider usability a minor concern compared to the massive task of creating functioning, bug-free software. Usability must be an organizational concern. The entire team—from management to marketing—must make usability a priority in all stages of the product life cycle.

A great deal of interesting work on usability is being done on the graduate level at the University of California, Berkeley's School of Information Management and Systems. Our interdisciplinary program emphasizes human factors in many of its classes. Students are taught user-centered user interface design and best-practice usability test methods. I invite Mr. Garfinkel and *Technology Review*'s readers to learn more about the program at www.sims.berkeley.edu.

MARY TROMBLEY
University of California, Berkeley
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Management and Systems
Berkeley, CA

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I AM GLAD TO DISCOVER THAT I'M NOT the only one who is perplexed by the notion that online retailers cannot filter credit-card numbers. I remember one site a few months ago where I typed my number with spaces, as there was no warning to the contrary. Not only did the vendor wait until I submitted the form to chastise me for being such an idiot, it went ahead and cleared all the fields in the form! As a programmer, I am always cognizant of the poor souls who must deal with my applications all day long. The effort it takes to make the interface as pleasing as possible more than pays for itself in operator morale and productivity. But there seems to be a corporate mindset in which it is better to spend time training the operators on the idiosyncrasies of a hastily written program than to make the program more intuitive in the first place.

BRETT GORDON
Agilent Technologies
Santa Rosa, CA

I WORK IN THE APPARENTLY FUTILE endeavor of getting clients to see that usable interfaces translate to dollars and sense online. It's a pity that the financial markets seem to link Amazon.com's lack of profitability to the company's focus on user-centered design, when in fact the dot com's financial situation has more to do with bad business decisions concerning growth, product offering and distribution.

If only we could figure out a way to talk to clients who don't have some of Amazon's woes, clients who are already profitable. If only we could get them to see that they could be even more so if they would satisfy their customers. When is someone going to do a serious return-on-investment study of a company that does usability and isn't Amazon? It's just too easy for clients to fall back on, "Well,

yeah, but they haven't made a profit, so who cares about their user experience?"

DEB FILLMAN
Watertown, MA

I ENJOYED READING SIMSON GARFINKEL'S piece on the importance of usability for site designers. It's a very important topic. However, I wish he would've mentioned some of the great work that is being done in this area and some of the resources online that can help designers achieve better usability (other than the obvious act of copying successful competitors' strategies).

There's some great work at the University of Maryland under the direction of Professor Ben Shneiderman in this domain. My own research focuses on how people find information online (whether for shopping or otherwise), and I'm finding that most sites (again, e-commerce or not) make clear navigation for users quite difficult.

ESZTER HARGITTAI
Sociology Department
Princeton University
Princeton, NJ

SIMSON GARFINKEL IS RIGHT ON THE mark regarding software that people use for the first time. It must be intuitive, simple and commonsensical. Indeed, Amazon.com is good in those respects.

His example of the credit-card number is well taken. Years ago, the AT&T study on telephone numbers showed that the three-by-four grouping gave the best results for memorization. As for the 16-digit credit-card number, try typing the number in one continuous string without reading it several times to make sure it is right. Also, when I have to give the credit number over the phone, I read it in blocks of four with pauses. Very seldom does the operator have to verify it.

BOB ZILLER
New Richmond, WI

Overdrive

AFTER READING THE JUNE 2001 "WIRED + Wireless" issue, I can see it all: a soccer mom with five or six kids screaming in the back seat of her minivan playing video games while she talks on her cell phone at 112 kilometers per hour, checks for e-mail on her in-dash Internet display, watches the stock ticker on her cyborg eyepiece, all the time talking to OnStar to find a burger joint for the team and maneuvering around the road crews installing high-capacity cable for the "last mile." What will we do with all of that bandwidth? How about finding a way to pump some common sense down a few of those optical fibers!

BARRY PEARLMAN
Chesterfield, MO

I READ ROBERT BUDERI'S ARTICLE ON "The Commuter Computer" (*TR* June 2001) with interest. The technophile in me is intrigued; the other part says, Oh please! I *want* to be out of touch at times. I don't care about sport scores; my portfolio is in it for the long haul—so stock quotes make no difference; and I already have a home, an office and a handheld computer. Why would I want greater access to e-mail? Not to mention the distractions. Won't idiots drive into oncoming traffic over a "Dear John" e-mail? Or when their stock options plummet into worthlessness? Or at the notification of an income-tax audit? Why not just autopilot vehicles under the direction of satellite computer systems? That way, The System will know where you are at each moment and whether you're on schedule; oh, such opportunities for targeted advertising and surveillance.

M. H. DOLAN
Atlanta, GA

Linguistic Labors

BEFORE THE PAST CENTURY'S TRANSFORMATION of media delivery mechanisms, it was true that losing the capability to utter words severely limited one's ability to communicate ("Waiting for Linguistic Viagra," *TR* June 2001). But today, multiple media deliver content, most of it visual. We routinely read and respond to e-mail from people all over the world without giving much thought to the fact that we are not speaking a word of it. We can browse the Internet for hours without opening our mouths.

Our linguistic input is increasingly received via visual media. On the surface then, it appears that it would be easier to be deaf than blind. That is, until the next wave of interface devices replaces the keyboard and mouse with voice interaction.

JOHN PAPANDREOU
Washington, MI

I WAS A BIT DISMAYED BY COLUMNIST Michael Hawley's assertion that, for a child, it is better to be blind than deaf because "hearing is the primary channel through which we receive language." Language is not acquired only through hearing and speaking. Language acquisition is dependent on input, which can be either auditory or visual. Many deaf children are deprived of this input because their parents, educators and doctors cannot decide on the best modality until it is too late.

JULIE HOCHGESANG
Los Angeles, CA

Michael Hawley responds:
I agree. When channels to language learning, and when reasons for language learning, are cut off, the learning doesn't happen or is deeply impeded. Unremedied, the linguistic poverty of computers will also affect the rest of society.

My "blind versus deaf" comment was an analogy intended to spotlight the challenge of development in an environment that is cut off from a sensory realm. Human communication is a rich mix of modes. We gesture and see. We touch and feel. We talk and listen. There is no question that losing a mode impedes one's ability to learn and grow with a community. Computers do little of that. I was pointing out that, rightly or wrongly, deaf children very often have a much harder time coming up to speed with language, because so much of linguistic and cognitive knowledge flows through sound. But my main argument is that the computer culture is just not doing the extra work required to provide a rich linguistic flow through computers. The Internet is still in its infancy, and this may be a crucial stage in computer linguistic development, too.

Video on Demand

I THINK CLAIRE TRISTRAM IS INCORrect, in "Broadband's Coming Attractions," that there will never be a market for video on demand (*TR* June 2001). I rent videos, watch the previews, go to the rental store and am lucky if they have 25 percent of the movies that appeared in the previews. I would gladly pay to have a movie download to my TV's hard drive while I'm sleeping, so I don't have to deal with traffic, people or poor selection. I don't care in which order the bits arrive

or how long it takes. I'll pay the $3.95 to never worry about returning the video late. Once people are connected and the services are available, they will learn to work around the current shortcomings of the Net.

ANDREW DAOUST
Anchorage, AK

The Test of Time

DAVID VOSS'S STATEMENT THAT "ROUGHLY speaking, faster clocks mean faster computing" ("Silicon Lasers," *TR* June 2001) assumes that a faster clock speed is the major factor in computing power instead of only one of many. It is a common misconception that a one-gigahertz processor is inherently faster than a 500-megahertz one. What most people fail to understand is that the architecture of the chip and the entire system are far more important than simply the clock rate. Such items as the amount and speed of the cache memory, for instance, will play a far more significant role in the power of a computer than even a 200-megahertz jump in clock speed. This is why, for example, a PowerPC processor running at 500 megahertz can be as or more powerful than a 1.2-gigahertz Intel processor. I find that too many individuals purchase computers under the false assumption that the faster a processor the better. I would love to see this myth debunked.

JASON COLLINGE
Vancouver, British Columbia

Mobile Reality Check

I COULD NOT AGREE MORE WITH ERIC Knorr's piece "Mobile Web vs. Reality" (*TR* June 2001). I'm a freelance writer in Europe, and I've never seen anyone make the business case for 3G (third-generation digital cell-phone networks) and why we need it.

The real reason why the industry came up with the idea of implementing 3G in the first place was that they were running out of 2G capacity. But the new spectrum boosts bandwidth by two orders of magnitude or thereabouts, so the only way to sell it is to tell consumers that they need high-speed data services. The whole thing is totally brain damaged.

BOB EMMERSON
Eindhoven, the Netherlands

Libraries on Show

THE CONFLICT BETWEEN DIGITAL publishers and libraries can be resolved, but this is one of those rare situations where compromise appears to offer the worst resolution ("Looting the Library," *TR* June 2001). I propose that, instead, both sides get their way.

Congress should pass the legislation that the digital publishers are putting forward (publications have total control over all use) but limit it to three years from the date of first appearance. After three years, digital content goes into the public domain, where libraries and users can do anything they like with it. This is similar to the old 17-year lifetime for patents, but scaled back to a suitable lifetime for publications.

WAYNE WILNER
Bradenton, FL

I THINK THAT THE CONCEPT OF TRYING TO pay-per-view a book or other publication is a blatant attempt at profiteering from something that has always been free. What the publishers need to invest in is a form of protected document that's less like a "pay-per-view" and more like a "pay-per-copy" file. It would be unable to be copied, modified or in any way manipulated aside from transfer or destruction.

In this manner, libraries could hold e-documents in the exact same way they hold them now, and publishers could stop griping about losing money they never even earned in the first place.

FEILDING ISAACS
Lexington, KY

REGARDING "LOOTING THE LIBRARY" BY Seth Shulman: libraries don't have the budgets for the pay-per-use model for information content that publishers are seeking. If profits are the point, though, libraries could still create the effect the publishers are after. Publishers will, for example, pay libraries to showcase their books. They could also let you check out the electronic versions of books and journal articles for free a couple of times; after that there would be a fee of some kind.

As we plunge into the digital realm, this is what publishers want—a way to control the extent and duration of users' access to their books and magazines. The libraries don't have to abandon their mission to provide free access to books and magazines, just update the "effect" of their existence to allow for synergy with publishers.

NEIL CALLE
Quincy, MA

A Strange Brew

THE SPIRIT OF INNOVATION THAT LED TO the creation and deployment of the Coffee Cam as described in "Trailing Edge" (*TR* June 2001) is remarkable—in more ways than one. If one calculates the expense for programming, equipment and labor to make the device operational, it surely would exceed the cost of purchasing a second coffee maker to deploy elsewhere in the building. In fact, the expense may have afforded most of the departments in the building a new device for brewing fresh coffee. This illustrates the phenomenon of a technology generating its own need, but also illustrates that not all the "needs" are legitimate, nor are technologically inspired solutions the most elegant or effective.

DAVID WENDT
Concord, CA

Corrections: A one-gigabit-per-second communications link like that described in "Breaking the Metro Bottleneck" (*TR* June 2001) would be able to transmit the contents of a CD in as little as five seconds—not in "less than a second," as our article stated.

In Eric Knorr's "Mobile Web vs. Reality" (*TR* June 2001), Tom Crook, director of technology research for Sprint PCS, is quoted as saying, "I don't see us doing 3G anytime soon." The quote should have read, "I don't see us doing 3X anytime soon."

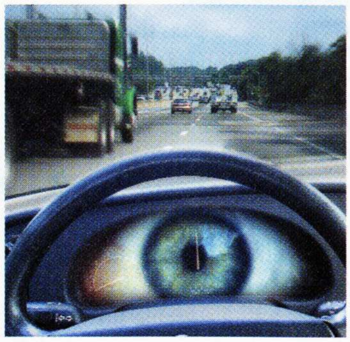
The telecommunications industry has used the term 3G to refer to full broadband wireless communications, at five megahertz bandwidth—a leap ahead from 2.5G narrowband transmissions. Some telecom companies, however, describe 3G as an evolving state with several levels. The first (lowest bandwidth) is 1X, offering speeds of 144 kilobits per second; the most advanced (broadest bandwidth) is 3X. In bringing this matter to our attention, Jennifer Walsh, group manager at Sprint PCS Media Relations, wrote that "3G1X is the first of a four-stage migration path that will enable Sprint PCS to upgrade to 3G."

PROTOTYPE

STRAIGHT FROM THE LAB: TECHNOLOGY'S FIRST DRAFT

Painless Screws

Ten percent of fractures require reconstructive surgery that uses titanium plates, screws or pins to realign bones. With these orthopedic implants comes the risk of infection and chronic pain. And once a fracture heals, a second surgery is required to remove the metal parts. However, MIT engineers have developed a synthetic bone implant that would fuse with natural bone in the body during healing. Coinventor Edward Ahn took a synthetic biocompatible material called hydroxyapatite in its powder form and synthesized crystals of the material less than 150 nanometers across. Packing these tiny crystals tightly together yielded a very dense material that is as strong as metal implants, stronger than other synthetic bone now available and 30 percent cheaper to make. Unlike metal implants, the new synthetic bone is defect free, poses little risk of infection and doesn't need to be removed. Ahn launched Angstrom Medica in Cambridge, MA, to commercialize the technology; he hopes to have its first orthopedic screws on the market in about a year.



VITO ALUIA

Wake Up!

Asleep-at-the-wheel drivers are a deadly menace. But the drowsy-driver detectors that have come out of some labs have serious flaws. Lane monitors sense when a car is drifting astray, but by then the driver is already asleep. Eye-blink and head-bob sensors work well, but some people can actually fall asleep with eyes open and heads upright. The Johns Hopkins Applied Physics Laboratory has built a drowsy-driver detector that promises to be less easily fooled because it looks at overall body motion plus eye blinks. A windshield-mounted radar device scans the driver and detects motion, feeding the data to a program created by a team led by Henry Kues. When the driver first sits in the car, the program takes a baseline measurement of such normal movements as fidgeting, radio tuning and head turning. When movement slows and ceases—an indication that sleep is imminent—the program focuses on eye blinks. The lab is trying to license the technology.

The Well-Mannered Cell Phone

You're engrossed in a movie at the Cineplex when your cell phone starts vibrating. Do you take the call—and irritate fellow filmgoers? Les Nelson at the FX Palo Alto Laboratory (the research lab of Fuji-Xerox) has developed a less intrusive solution: Quiet Calls, a device that, at the push of a button, puts through inconvenient calls but first plays a prerecorded voice message, such as, "I can't talk now, but I can listen—go ahead." Quiet Calls could eventually be built into cell phones; the prototype is an attachment that plugs into the phone's voice input jack and that provides a three-button keypad to execute up to nine responses *(photo)*. Why not just use text messaging? Says Nelson, "Sometimes you need voice interaction."

COURTESY OF FX PALO ALTO LABORATORY

Spectacles to Spec

When your eyesight blurs, the local optician can whip up a set of lenses quickly. But in rural areas of developing countries, corrective lenses are hard to come by. MIT instructor Saul Griffith has designed a solution: a briefcase-sized kit that uses an ordinary kitchen appliance to make spectacles to spec. "Essentially, it's an orange press that can print lenses in the field at extremely low cost," Griffith says. The kit uses standard safety glasses, costing less than a dollar, which are coated with an epoxy. The press imprints a prescription set of light-focusing concentric ridges. In minutes, out pops a flat Fresnel lens akin to those used in stoplights *(photo)*. Students from Harvard Business School are working on distributing the lensmaker where it is most needed.

DANIELLE SMITH, MIT MEDIA LAB

Power Miser

Wireless networks that give you access to e-mail or the Web from anywhere in your home or office are, it seems, becoming ubiquitous. But the electronic receivers that allow laptops and personal digital assistants to pick up wireless data signals are power hogs, reducing the already short battery life of portable computers. University of Southern California electrical engineer Anthony F. J. Levi has developed a receiver that he says could extend battery life as much as tenfold.

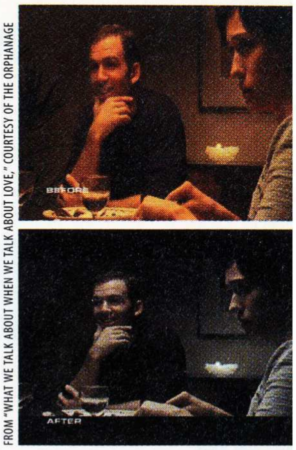
The key is a microphotonic disk that converts the microwaves used by these wireless networks into light waves. This low-loss optical signal is easily converted to electronic form using existing low-power technology. (Conventional all-electronic microwave receivers must consume lots of power to prevent signal loss.) While the new receiver is still in the lab, Levi expects commercial applications to emerge by year's end.

Cool Stamped Chips

Most microchips are made by using light to create patterns on silicon surfaces—a process requiring sophisticated equipment costing tens of millions of dollars. A cheaper chip-making process involves coating the silicon surface with a polymer, heating the polymer until it softens and then mechanically stamping it with a patterned mold. Chemicals dissolve the stamped polymer where it's thinnest, exposing the silicon beneath and etching the pattern into it. A drawback: the polymer can be stamped only once, since reheating deforms it.

Researchers at the Seoul National University in Korea may have brought imprint lithography a big step forward. The key development: doing away with the heating step, which they discovered to be unnecessary. Even at room temperature, chemical engineering professor Hong H. Lee showed, the polymer flattens far more under mechanical pressure than had been anticipated. Repeating the process on the same surface with a different mold allows more complex patterning. The technique, still at least two years away from commercial readiness, could drive down the costs of micro and nano devices.

Cinematic Video



FROM "WHAT WE TALK ABOUT WHEN WE TALK ABOUT LOVE," COURTESY OF THE ORPHANAGE

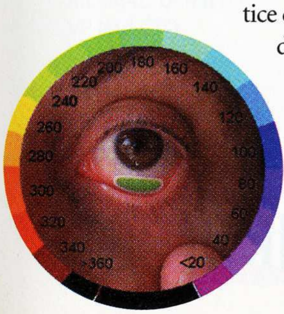
Digital video has lately provided independent filmmakers with an inexpensive alternative to shooting film. The trade-off: it looks like video—that is, flat, and lacking film's painterly quality and versatility *(top)*. But San Francisco-based The Orphanage has developed software that gives video the richly textured look of film *(bottom)*. The software gets rid of video's distracting scan lines, softens its oversharpness, and adds lighting effects and color correction. The finished result can be converted to various formats, including streaming video and 35-millimeter film, with no loss of quality. This electronic manipulation is far less expensive than working with film. The technology will be showcased next month with the theatrical premiere of *Chelsea Walls*, a feature that was shot entirely on digital video. When will the camcorder brigade have a consumer version? "We're working on it now," says Scott Stewart, The Orphanage's cofounder.

No More Needles?

To free diabetics from daily pinprick tests, a startup called Sentek Group has come up with a new, noninvasive way of monitoring diabetes that doesn't require any pricey machinery. The Pittsburgh-based company has developed a cheap, disposable contact lens that hides behind the lower eyelid and changes color according to the glucose level of the tear fluid. Too much sugar, and the entire lens turns red; too little and it turns violet *(photo)*. A patient matches the lens hue to a calibrated color wheel inside a compact mirror, with each shade corresponding to a glucose level.

Chemist Sanford Asher at the University of Pittsburgh created the material—a porous gel embedded with charged polystyrene particles. The nanometer-sized balls form a lattice that expands and contracts with the hydrogel. Sentek infuses lenses made from this gel with protein molecules that bind to glucose in tear fluid and cause the lens to swell. As the spacing in the polystyrene lattice changes, the material diffracts light at different wavelengths to produce a color change. Sentek hopes to have a product ready for human testing by late 2002.

COURTESY OF SENTEK GROUP



Permeable Parking

Rainwater running off of a concrete or asphalt parking lot carries oil and other contaminants into storm drains, fouling waterways. New "permeable pavement" designs from North Carolina State University could make parking lots less polluting.

Construction proceeds in layers. A water-permeable polymer fabric is laid over a gravel base. Then heavy-duty interlocking plastic rings are embedded in sand layered over the fabric. More sand tops the whole structure. Rain filters down through the lot rather than running off of it; pollutants are carried into shallow ground water where microbes break them down. Researchers have been studying a city-owned lot in Kinston, NC, for two years and plan to construct another in Wilmington, NC. Bill Hunt, a North Carolina State water management engineer working on the projects, says that the design should be less prone to potholes than earlier efforts with porous asphalt. Although not durable enough for busy parking lots (think McDonald's), the new pavement could serve well in daily or long-term lots like those at airports. Hunt says other local governments, as well as homeowners, have expressed interest.


KARL DEBLAKER, NC STATE UNIVERSITY

Tuned-in Lasers

Fiber-optic networks carry data as different-colored pulses of laser light. When adding data to an optical signal, it helps to be able to tune the transmitting laser to a color not in use. Two hitches, though: tunable lasers are expensive, and they aren't widely offered commercially. SRI International in Menlo Park, CA, says it has devised a means of creating a tunable laser that should make the technology cheaper and more available.

Rather than build a device from scratch, SRI has found new ways to employ off-the-shelf components, says Pajo Vujkovic-Cvijin, lead scientist on the company's Chameleon Project. For example, the SRI laser uses a minuscule heater—the width of a strand of hair—to tweak the wavelength of light by adjusting its temperature. SRI is keeping mum on most details surrounding the project until two patents receive approval, which should happen this fall. But the company is talking with 14 optical-networking equipment manufacturers about licensing possibilities.

The TR100 Call for Nominations

Do you know a brilliant young innovator? We're taking names!

Technology Review is seeking nominees for the heralded TR100—one hundred young men and women whose technical work promises to have an impact on the 21st century. Candidates must be under age 35 on Jan. 1, 2002, and their pursuits should exemplify the spirit of innovation. *Technology Review* will profile the finalists in a 50-page special report in its June 2002 issue, and recognize their accomplishments during an exclusive conference and gala awards program, where the magazine will also present its coveted "Innovator of the Year" award. A distinguished panel of judges—eminent technologists including two Nobel laureates—will evaluate nominees.

Technology Review announced the inaugural TR100 class in November 1999. In two short years these innovators have begun to change our world. The 2002 class will broaden the fraternity. Help us find these rising stars!

Anyone can nominate a candidate, including him or herself, by using the simple online form at www.technologyreview.com.

DEADLINE FOR SUBMISSION
October 1, 2001

AN MIT ENTERPRISE
TECHNOLOGY REVIEW

TR100

THE YOUNG INNOVA WHO ARE CREATING TH

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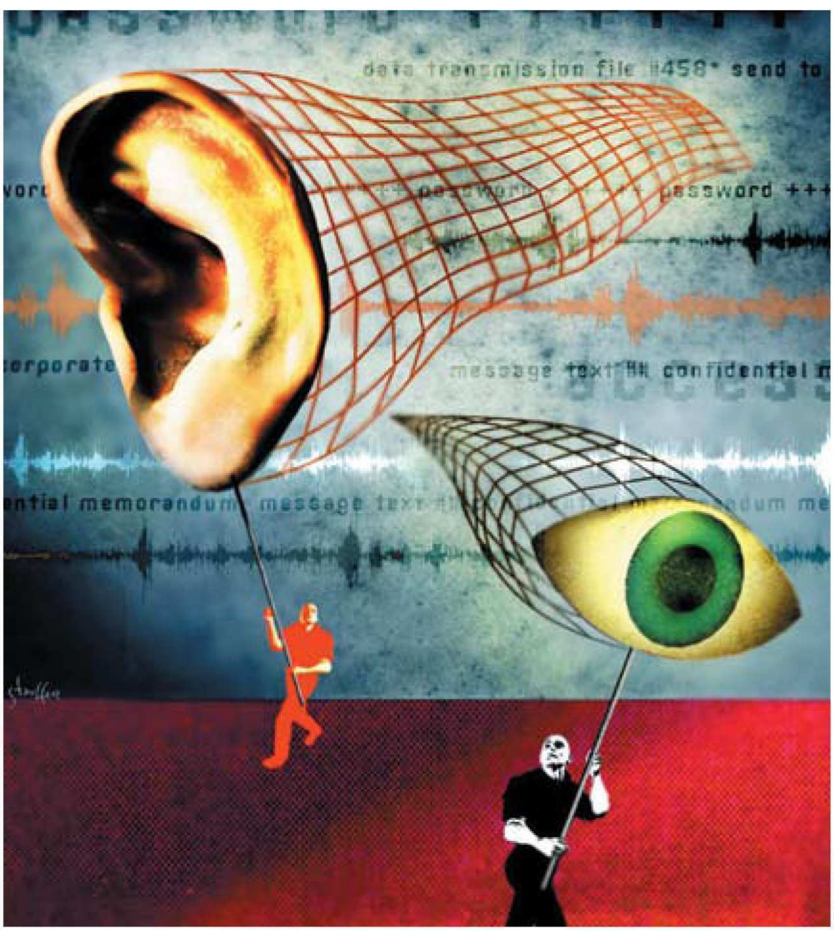
The Undefended Airwaves

Can our cell phones, laptops and pagers ever really be secure? Or are our phone calls, the data on our hard drives, and the messages that we receive inevitably going to be an open book for any suitably motivated government spy—or teenaged hacker?

Certainly, nothing can ever be 100 percent protected. Sadly, though, the makers of portable computing devices and wireless communications systems have led us down a false path by failing to make security a top priority. For more than a decade, cryptographers have possessed strong encryption techniques that could virtually guarantee that data falling into the wrong hands—through a stolen laptop, say, or an intercepted radio signal—would be impossible to decode. Unfortunately, these techniques have not made it from the lab into the mainstream.

As a culture, we have little experience with secure communications—and a lot of experience with communications security gone sour. Time and again, wireless equipment vendors and providers have been shamed by the security failings of their products. The analog cellular telephone systems of the early 1980s lacked any protection at all; a $200 scanner from Radio Shack would let you listen in on anybody's cell-phone conversation.

Rather than endow their products with strong encryption, the wireless companies turned to Washington for help. The result was the 1986 Electronic Communications Privacy Act, which effectively made it illegal to listen in on cellular-phone calls. But the legislation didn't stop snooping: after the law's enactment, House Speaker Newt Gingrich, Virginia governor Douglas Wilder and even Prince Charles all had their wireless communications intercepted.



BRIAN STAUFFER

The cellular industry paid dearly for its decision to seek security from Congress rather than cryptographers; just as phone calls were sent through the airwaves without encryption, so were the account numbers used for billing. The 1990s saw an explosive rise in the incidence of cellular fraud, with thieves sniffing account information in order to "clone" phones—that is, have one phone bill to another phone's account. According to industry estimates, phone cloning was costing the industry several hundred million dollars each year by 1997.

Unfortunately, many decision-makers have learned the wrong lesson from these chronic failings: instead of resolving to deliver more secure systems, many seem to have concluded security and privacy are elusive at best—and that scarce resources are better spent on other goals. This spells real danger as wireless devices become a greater part of our economy. All of the large-scale wireless paging and data networks deployed in the 1980s and '90s repeated the cell-phone industry's mistake and eschewed encryption. Today these networks are the basis for popular wireless products like pagers and the Palm VII personal digital assistant. Messages sent using these systems can be—and are—intercepted with ease.

What's worse, it can be nearly impossible for a consumer to make an informed decision about a product's security. Consider the Palm: all Palm-OS-based computers let you make certain records "private," meaning that they shouldn't be visible unless a password is entered. This password could be enforced with encryption,

but it isn't: last September, the Cambridge, MA, computer security firm @ Stake announced that anyone with physical possession of a person's Palm could reverse-engineer the password.

There are a few signs of enlightenment. The digital telephone services offered by Sprint PCS and VoiceStream use encryption to protect both billing information and the content of calls. The BlackBerry two-way communicator encrypts each message before transmitting it. But security all too often remains an empty promise. AT&T's wireless telephones allegedly offer encryption, but when I turned on the feature, my telephone stopped working. I called AT&T and was told "voice privacy isn't supported." When I was a Metricom customer and enabled the advertised encryption feature, my connections routinely got dropped. The company's advice: if I wanted more reliable service, I should turn the encryption off.

Industry officials say that one reason they don't spend the extra money on encryption is because wireless users don't care much about it. Whatever validity that viewpoint once had is fading, though, as more and more of our activities depend on wireless networks. Consider those high-speed wireless local-area networks now being deployed by many homes and businesses. Earlier this year, a friend of mine in Boston installed a wireless network card and found that he could tap into an office across the street. My friend now "borrows" the firm's high-speed Internet connection at night after the people in the office go home. That's a pretty benign imposition, but the security hole allows him far greater access; he could, if he chose, browse the company's files and read its employees' e-mail. And this problem is widespread: earlier this year, Silicon Valley computer consultant Peter Shipley made headlines for driving around town with a laptop in his car and mapping all the wireless networks that he could sniff.

For years, the vendors of wireless local-area networks have advertised their equipment as being secure. The systems use spread-spectrum technologies—a technique that is supposed to make the radio signals incredibly difficult to intercept. The systems also have a form of password protection. Finally, equipment makers say, most wireless local-area networks support some kind of over-the-air encryption.

The wireless industry has dropped the ball on communications security, giving up on encryption and leaving us vulnerable to snooping.

Don't believe these assurances. Spread-spectrum broadcasts are easy to pick up with a wireless network card specifically designed for such transmissions. Similarly, the password systems offer little security: many wireless network cards let you set the password to "ANY," which tells the card to connect to any network it finds. You can also use a "site monitor" program that comes with many cards to display the passwords of every local network that it hears. And it is so difficult to set up encryption on these systems that most users simply don't go through the trouble.

Why weren't these problems anticipated and corrected when the wireless local-area network standards were being developed? One big reason is that the engineers on the standards committees never sought out advice from cryptography experts.

Cryptographers, as a whole, haven't done much to inspire confidence. Throughout much of the 1990s, many were locked in a battle with the U.S. government. The government was pressuring computer companies to put weak cryptography into their products, arguing that strong encryption would undermine the country's intelligence-gathering and crime-fighting capabilities. Many cryptographers spent their days breaking these weak systems to show just how vulnerable they were. Unfortunately, this experience has left a curious legacy: many engineers now believe that with computers getting faster and faster, it is only a matter of time before cryptographers will be able to crack *any* cryptographic system.

This attitude is nonsense. For years, cryptographers have known how to make algorithms that are so strong that it is inconceivable they will be cracked for a very long time—as in, not before the sun engulfs the earth. That's because the difficulty of cracking a key goes up exponentially with the size of the key. A small network of Pentium computers that can search a billion keys a second can crack a 40-bit encryption key in 18 minutes. Double the key length to 80 bits and that network would have to gnaw away at it for quite a while longer—about 38 million years. With 128-bit encryption (technology that has been available for more than a decade), it would take a billion of these networks roughly 10 trillion years. That's about as absolute a guarantee of security as anyone is likely to need to guard his or her cell-phone conversations.

If the wireless industry understands this, it is doing an odd job of showing it. The current plan for many Bluetooth wireless devices is to base security on a four-digit PIN code—the equivalent of a 14-bit encryption key. Although the standard allows longer PINs, equipment vendors don't want to make their first-generation Bluetooth systems too difficult to use.

As long as people believe that even the most advanced privacy-protecting technologies can be readily compromised, they won't demand better security—after all, why bother? But it is folly to let pursuit of the perfect become the enemy of the nearly perfect. Before we give up on strong encryption and excellent security, we should at least give it a try. TR

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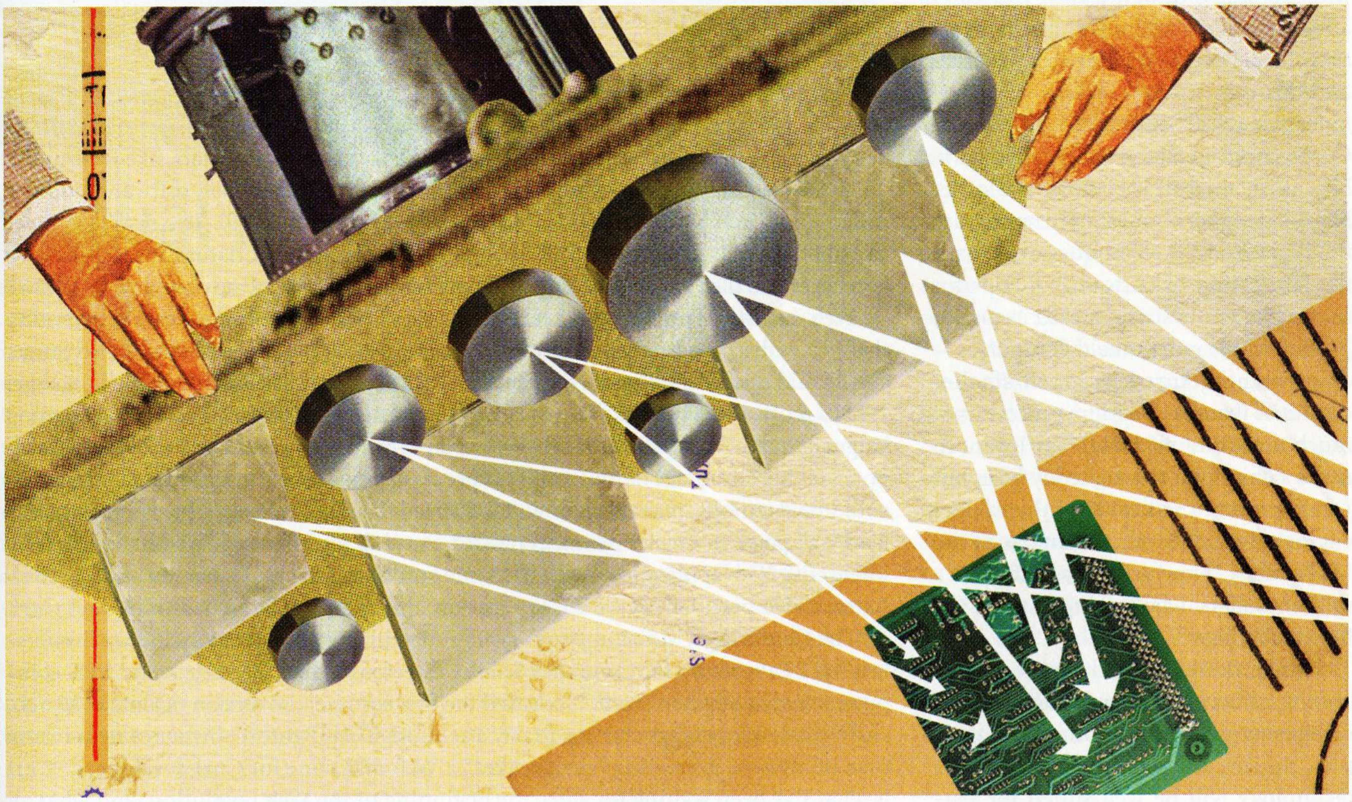


JASON HOWARD STATTS

Lithography Unmasked

Researchers pursue a cheaper way of designing and fabricating computer chips

HARDWARE | As consumers come to expect that everything from cell phones to stuffed animals will pack significant computing power, manufacturers are under pressure to churn out ever faster and cheaper microchips. But making computer chips using photolithography—the standard manufacturing technique—is wildly expensive. A significant part of that cost is the stencil-like "masks" that filter the light beam used to pattern millions of transistors onto a chip. Indeed, making a single silicon chip can require as many as 30 masks costing more than a million dollars—and as the transistors on a chip continue to shrink, the cost of the masks only grows.

No wonder, then, researchers are racing to develop ways to do away with masks entirely. One of the most promising efforts, led by Henry Smith, director of MIT's NanoStructures Laboratory, uses an array of tiny mirrors, each just 16 micrometers across, to direct light through microscopic lenses; each lens focuses a beam of light to a spot on the silicon wafer, and the more powerful the lens, the smaller the spot. By tilting individual mirrors back and forth, a computer can turn individual beams on and off as the whole setup scans across the wafer. With as many as a million mirrors, the system could create the same complex pattern on the silicon chip that would normally require a series of masks.

So far, Smith's group has used the system to pattern chip features 350 nanometers wide—40 percent wider than those on today's best chips. But computer simulations predict the MIT technology can generate features as small or even smaller than those derived using conventional lithography by switching to shorter wavelengths of light.

At the University of California, Berkeley, a group led by electrical engineer William Oldham is taking a similar approach; but where the MIT group has focused on increasing the power of the lenses to make smaller features, the Berkeley researchers are reducing the size of the mirrors. Without increasing the power of the lenses, "to get smaller patterns you need smaller mirrors," says Yashesh Shroff, a graduate student in Oldham's lab.

Currently, Oldham's team is making mirrors measuring only one micrometer across. "Nobody has ever made such tiny mirrors before," says Shroff. Within five years, he adds, the researchers hope to have a complete system that can etch features 50 nanometers wide or less into silicon chips.

Maskless technologies could give chip designers unheard-of flexibility. "If you want to test a design a day, you can't afford to build a million-dollar mask set a day," says Dan Herr, director of materials and process science research at the industry-backed Semiconductor Research Corporation in Research Triangle Park, NC. With micromirrors, on the other hand, a designer could simply reprogram the array. And the technique could make the fabrication of customized chips for things like synthesizing speech in toys or playing MP3s in handheld computers—chips manufactured in much smaller quantities than, say, Pentium processors—much more cost effective. "Say I want to make a chip for a talking teddy bear, but I only expect to sell 2,000 of them," says engineer David Carter, a member of the MIT group. "Now, with mask costs at a million dollars, who's going to pay $500 for a teddy bear?"

Greater flexibility and lower cost could also be a boon for other industries pursuing emerging applications of lithography. Smith, for example, thinks his technology will be well suited for patterning the chambers and channels that help process biological samples in microfluidic chips, which could be used for drug discovery or in handheld diagnostic devices.

Observers suggest that the MIT team is the closest to a product that would replace masks; the researchers hope to have a commercial mirror-and-lens device for chip prototyping on the market in a year or two. Still, chip makers are also taking notice of the lithography efforts at Berkeley, Stanford University and the University of Texas at Austin. "Until about two years ago, all of this maskless technology was seen as very blue sky," says Herr. But advances in computer software as well as technologies for fabricating things like micromirrors—coupled with the growing cost of existing production methods—could bring maskless lithography out of the lab and into fabrication plants within four to five years, Herr says.

If and when that happens, it will bring down one more barrier to computing innovation. **—Alexandra Stikeman**

Catching the Curl

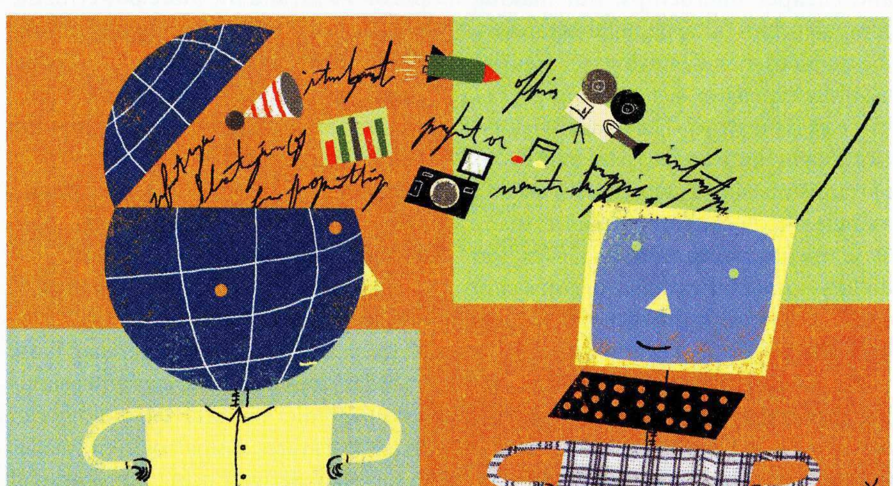
A new language changes Web surfing

INTERNET | When the World Wide Web debuted in 1991, Web pages were basic: text only, black on gray. Developers have since added animation, sound, video and interactivity using new programming languages, like Java, and file formats, like RealAudio. To allow Web browsers to handle all these languages and file types, software modules called "plug-ins" have proliferated; there are now more than 140. The result: a Tower of Babel for Web developers. And because the burden of negotiating among all these languages and file formats falls largely to network servers, downloads can slow to a crawl.

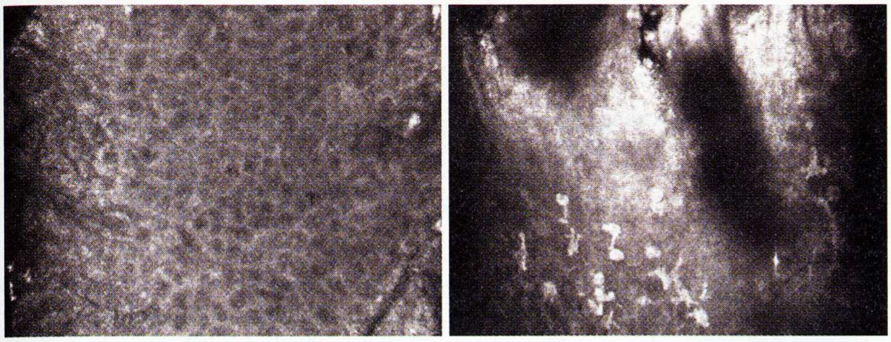
Web inventor Tim Berners-Lee and several of his MIT colleagues are reinventing the Web with a new language called Curl. Combined with a single plug-in called Surge, Curl could enable developers to create multifunctional sites using a single language. What's more, the system moves so-called compiling tasks—turning raw programming language into a form your browser can display—from busy servers to a user's own computer, taking advantage of underutilized processing power at the surfer's end. The result could be a tenfold increase in download speed. Curl also allows a browser to download Web pages in smaller pieces, as needed. Put it all together and "We can build a fully interactive Web application [with the same amount of data as] a banner ad," says Bob Batty, a vice president at Curl Corporation, the company launched to market Curl.

The Cambridge, MA, company was founded in 1998 by a team including Berners-Lee, MIT Laboratory for Computer Science director Michael Dertouzos and MIT computer scientist Stephen Ward. It released the first commercial version of Curl in March, and Web developers are starting to pay attention. Chris Banford, owner of new-media firm bSoftware, is creating "curlBreaker," a Web magazine for Curl developers. "Curl is what I've been waiting for since the beginning of the Web revolution, and what all the other technologies have fallen far short of," Banford says. David Smith, an Internet analyst at consulting firm Gartner Dataquest, agrees that the technology is sound but has doubts about the company's plan to charge commercial content providers based on how many people access content created using Curl.

So far, electronics giant Siemens has used Curl to build an intranet for its executives, and BTexact Technologies, the research arm of British Telecommunications, has committed to developing Web applications using the language. Curl Corporation, however, has more work to do to before its system becomes a Web standard; as of midsummer, the language and plug-in were available only for Windows. But with Unix and Macintosh versions under development, the company is driving steadily towards its goal: to deliver one unified technology for building the Web. **—Erika Jonietz**



JAMES YANG



COURTESY OF LUCID

Images from Lucid's VivaScope show normal skin (left) and a skin cancer called melanoma (right).

Virtual Biopsy

MEDICINE | Last year, doctors told 1.3 million patients in the United States that they had skin cancer. But still more people underwent painful biopsies—in which a suspect mole is cut off, sliced into thin sections and examined under a microscope—on what turned out to be healthy skin. A new laser-based imaging device could allow doctors to peer painlessly into the skin and diagnose growths without surgical biopsies.

The device is a descendant of a laboratory tool called the confocal microscope. By scanning a laser beam across a tissue sample and detecting the light reflected back, the desk-sized microscope can piece together highly detailed images of successive layers of cells, creating virtual slices through the tissue. Lucid in Rochester, NY, and Optiscan Imaging in Notting Hill, Australia, are adapting the microscope to the doctor's office. Ashfaq Marghoob, a dermatologist at Memorial Sloan-Kettering Cancer Center in New York who is testing Lucid's "VivaScope," is enthusiastic about the technology. "Instead of cutting out hundreds of moles, you can just scan them and follow any changes over time," Marghoob says.

Preliminary studies indicate that devices like the VivaScope and Optiscan's Stratum may be as reliable as standard biopsies in diagnosing many forms of skin cancer. Lucid senior vice president Stuart Itkin says the company aims to have a commercial model ready by May; Optiscan is planning to begin U.S. clinical trials around January. Itkin says confocal microscopy could be used to detect other cancers as well, replacing Pap smears and cervix and mouth biopsies.

Getting doctors to accept the new tool will be key to realizing that vision, though. That's why Harvard Medical School pathologist Martin Mihm, a consultant for Lucid, is developing software to make the microscope's images look more like biopsy slides. "If it's not familiar to pathologists, [it's] more difficult to use," Mihm says. But if the device developers can make the diagnostic tool simple and accurate enough, millions of anxious patients will have one less thing to fear. **—Naomi Freundlich**

Ultrahybrid

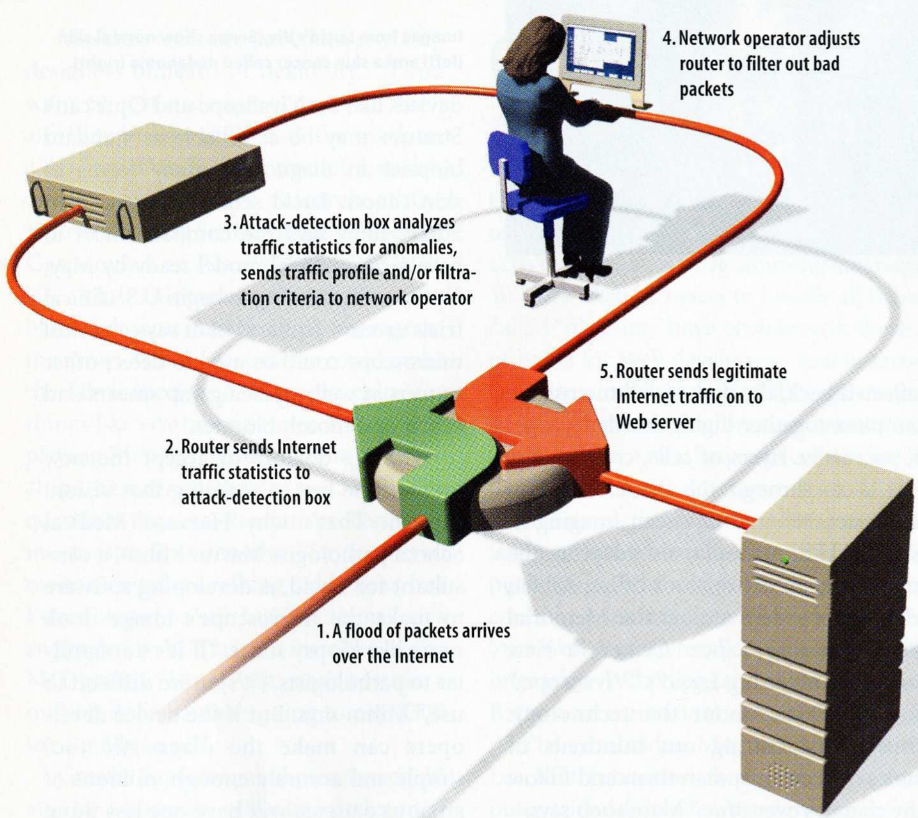
TRANSPORTATION | When General Motors' electric buses hit New York City's streets for a test run a couple of years ago, the company found that the new hybrid vehicles—propelled by a diesel generator and electric motors—burned less than half the fuel of a conventional diesel and created 90 percent less pollution. One hitch: the roughly 5,000 dollars' worth of batteries that mediated the flow of electricity between the generator and motor burned out after only a year. Now, GM plans to keep its hybrid buses rolling by replacing the batteries with a high-tech cousin of the capacitors that regulate power in electronic devices. The same technology may soon help make hybrid cars more efficient and affordable.

COURTESY OF MAXWELL TECHNOLOGIES

Unlike batteries, which store energy using chemical reactions, capacitors store power as static electricity—and so can charge and fire millions of times without wear. The *ultra*capacitors in GM's new buses outpunch garden-variety capacitors by incorporating carbon electrodes riddled with pores and fissures. Each gram of carbon provides thousands of square meters of surface area; more surface area means more charge can be stored. Ultracapacitors also charge in a flash—which could boost fuel efficiency another 10 to 15 percent, says Andrew Burke, director of the University of California, Davis's Electric Vehicle Power Systems Laboratory. That's because a hybrid recovers short bursts of energy each time a driver brakes. Whereas batteries can capture only 60 percent of a vehicle's braking energy, ultracapacitors grab over 95 percent. According to GM, swapping the new hybrids for the 13,000 transit buses that serve the top nine U.S. cities would save nearly 950,000 barrels of diesel fuel each year.

GM says PowerCache ultracapacitors from San Diego-based electronics manufacturer Maxwell Technologies will power its commercial hybrid buses, due to roll out in 2003. You might well find ultracapacitors under cars' hoods soon after, Burke says, beginning with the pollution-busting "light hybrids" that GM, Ford Motor and other automakers plan to introduce in 2004. This new type of gas-electric hybrid has a high-voltage electrical system, allowing it to cut off the engine at each stoplight, then use an electric starter to jolt it back to life when you hit the gas. Ultracapacitors could deliver that jolt without wear, meaning light hybrids could soon burn rubber without burning out the battery. **—Peter Fairley**

INNOVATION



SLIM FILMS

Stemming the Flood

New devices could protect Web sites from a common threat

SOFTWARE | Since January of 2000, computer saboteurs have knocked out some of the biggest sites on the Web—like eBay, Amazon.com, and Microsoft's Hotmail and Expedia—by flooding them with bogus Internet traffic. Unlike most computer sabotage, swamping a server requires no breach of security and little computer expertise. The inundating traffic is otherwise innocuous; there's just too much of it, coming too fast. And programs for launching these "denial-of-service" attacks—so called because the bogus traffic denies legitimate users access to the server—can easily be found online.

But new hardware from several U.S. startups could help sites identify attacks before their servers go under. The leading approach is to monitor a Web site's traffic, determine its typical ranges of activity and then flag suspicious fluctuations. "One thing about these attacks," says Rob Malan, chief technology officer and cofounder of one of the startups, Waltham, MA-based Arbor Networks, "is that they are *not* subtle." Indeed, they even look much different from the sudden surges of traffic that might accompany, say, an ad for your Web site that runs during the Super Bowl; in a denial-of-service attack, a few computers might download the same data thousands of times, for example. Once identified, bad traffic can be filtered out of the data stream.

When a packet of data travels over the Internet, it passes through a series of routers. Each router looks at the packet, reads its addressing and identification information, and speeds it on its way.

Flood Protection Firms

COMPANY	LOCATION	PRODUCT
Arbor Networks	Waltham, MA	Peakflow DoS
Asta Networks	Seattle, WA	Vantage System
Captus Networks	Woodland, CA	CaptIO
Mazu Networks	Cambridge, MA	TrafficMaster

Most high-end routers keep statistics on the traffic they see, so both Arbor and Seattle-based Asta Networks sell boxes that plug into routers, analyze their traffic statistics and alert network operators to any anomalies. The Arbor box, which reached the market in May, sends suggested criteria for filtering bad data along with the alert; Asta's device, released in June, instead sends an exhaustive profile of the suspect traffic.

Mazu Networks of Cambridge, MA, offers a variation on the theme: a device that taps directly into the data stream to observe the traffic whizzing by. The Mazu box isn't tied to any particular router technology and can, if necessary, investigate a packet's cargo, which routers don't examine. But unlike Arbor and Asta, it can't yet handle the top speeds of the fastest Internet connections available; and it requires a second device to filter bad packets. The Mazu system completed beta testing in April and was formally launched in June.

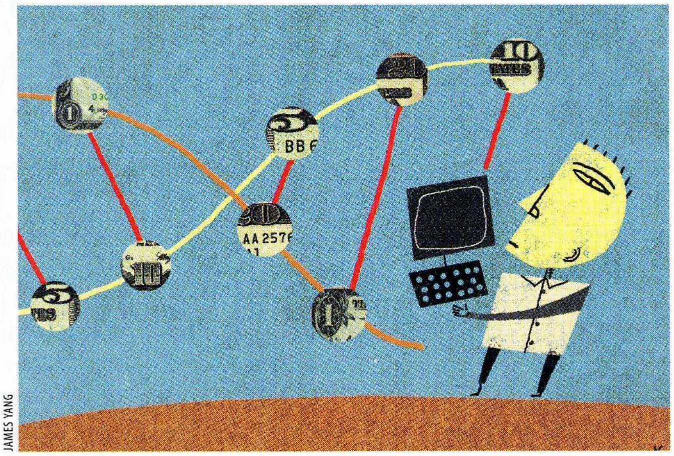
Captus Networks of Woodland, CA, takes a different approach. The Captus device allows network operators to set a rate limit on incoming traffic. When the limit is exceeded, the device sends standard Internet Protocol requests to all the computers connected to it, asking that they slow their transmissions. Computers generating legitimate traffic respond accordingly; malicious computers don't, and their traffic is then filtered out.

Some industry insiders worry that such close attention to each incoming packet could slow a network down. "I don't want another box inline to pass my packets through," says analyst Michael Rasmussen of Giga Information Group. But Zeus Kerravala of the Yankee Group believes the Captus device is fast enough to keep up with server traffic for "at least a year and a half to two years," and that "the technology will improve in that time." NASA's Ames Research Center and Exodus Communications of Santa Clara, CA, are currently evaluating the device.

With four new options to choose from, the Web's most popular sites should—for the time being—be able to shield themselves from vindictive 13-year-olds. **—Larry Hardesty**

Boom amidst Bust

Computing plus biology equals big money



JAMES YANG

BIOTECH | Amidst the ashes of the dot coms, one ember of the computing economy remains red hot: bioinformatics. The potential of the field—which brings the combined power of computers and biological data to bear on problems ranging from agriculture to drug discovery—is so great that otherwise technology-wary investors are continuing to back new startups, and deals in the area are taking off. One catch: a deficit of qualified people with the right blend of skills in computer science and molecular biology to staff the booming business.

"By almost any measure [bioinformatics is] growing," says David Searls, head of bioinformatics at GlaxoSmithKline. "You can look at number of positions; you can look at number of companies; you can look at academia." Indeed, deals between bioinformatics firms and other biotech or drug companies are on the rise, according to a recent report from Cambridge Healthtech Institute; 79 were inked in the first quarter of this year, compared with 55 for the same period in 2000. Leading the way was the sale of Kirkland, WA, bioinformatics firm Rosetta Inpharmatics to drug giant Merck for $620 million in May.

As investment has dried up completely in many technology sectors, the venture capital market has held for bioinformatics firms. "It's definitely decoupled from the downturn in technology funding," says Emmett Power, CEO of London-based Silico Research. Several bioinformatics companies have closed on funding in 2001: life-sciences peer-to-peer computing company Entropia received $23 million in second-round funding in January; Spotfire, a data analysis software maker, announced $15 million in additional funding in February; and life-sciences computing infrastructure provider Viaken Systems announced $13 million in its second round in June.

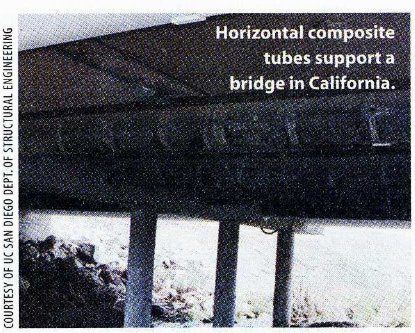
Staffing problems, however, threaten to put the brakes on the surge in bioinformatics activity. The field is so hot, says Nat Goodman, senior vice president of Cambridge, MA-based bioinformatics consultancy 3rd Millennium, that companies and universities alike can find only about half the number of people they need.

—Erika Jonietz

Bridge to Tomorrow

MATERIALS | It doesn't look much different from California's other arroyo crossings, but peek under the deck of the Kings Stormwater Channel Bridge on Route 86 in Riverside County and you'll find something surprising: plastic, carbon and glass where steel girders and reinforced concrete ought to be. The California Department of Transportation's recent completion of the bridge could mark the beginning of a move away from traditional construction materials in favor of lightweight, rugged composites.

Though "polymer matrix composites" (fibers like carbon or glass encased in plastic) have found their way into a smattering of smaller structures in the past decade, the new bridge is the first to face the test of highway traffic and long-haul trucks. It boasts a fiberglass composite deck with a thin veneer of special concrete supported by carbon-fiber composite tubes just 355 millimeters in diameter. The materials are so lightweight two men can do what normally requires a crane. That translates into faster construction, which is critical when a busy bridge is out of commission, says the Federal Highway Administration's Eric Munley, a composites expert. "If you can replace the thing in a week, you're going to be very interested in composites," Munley says.



Horizontal composite tubes support a bridge in California.

COURTESY OF UC SAN DIEGO DEPT. OF STRUCTURAL ENGINEERING

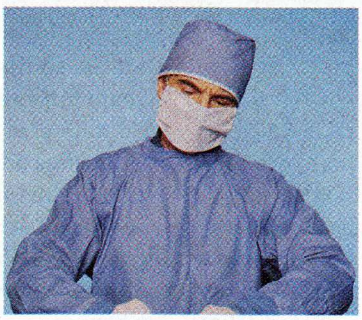
In fact, the Kings Stormwater bridge went up in one-third the usual time—but at twice the cost, because composites are relatively pricey. Still, says California Department of Transportation chief deputy director Jim Roberts, the materials' superior durability could make them worth the expense, not only for bridges but also for highway decking in areas where ice and salt readily do in steel and concrete. "All you have to do is get 20 to 30 years out of it, and you're way ahead of the game economically," Roberts says. His department is planning to begin another composite bridge in San Diego in mid-2002.

Jim Cooper, the director of bridge technology for the Federal Highway Administration, is also optimistic: "It's my belief that composites will form a major construction material in the future." But until the cost of composites comes down, the gap between present and future may be a difficult one to bridge.

—Lauren Gravitz

BUILDING AN E-BUSINESS INFRASTRUCTURE ISN'T BRAIN SURGERY.

IT'S MUCH HARDER.



"Now, this may hurt a bit."

THE AVERAGE DOCTOR is given fourteen years to master the art of brain surgery. To manage the implementation of an e-business infrastructure the average CEO gets all of twelve months. Twelve months to make or break a business.

It's no exaggeration. When infrastructures go down, companies go down. Networks clog up. Web sites crash. Business relationships suffer. Customers are lost. Infrastructure is not just an IT concern, it's a corporate concern. That's why even non-technical types need to understand the basics.

Unfortunately, when you have to connect databases, company Web sites, legacy systems, new servers, cell phones and PDAs, basics can very quickly become complexities.

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UPSTREAM

SPOTLIGHT ON A HOT TECHNOLOGY TO WATCH

Smart Home Care

New diagnostic devices could save an ER visit

EVERY YEAR, MORE THAN 50,000 Americans with diabetes must undergo foot or leg amputations. In many of these cases, poor blood circulation is the villain. Imagine, then, having socks with built-in pressure sensors that would alert you to put your feet up for a while. Researchers estimate that about three-quarters of diabetes-related amputations might be avoided with this kind of simple warning system.

Smart socks are just one example of the growing push to make high-tech home medical devices a part of our everyday lives. "Health care is coming home again," says William Herman, director of the physical-sciences division of the U.S. Food and Drug Administration's Center for Devices and Radiological Health. "This is one of the most—if not *the* most—rapidly growing segments of medical technology. It's driven by an aging baby boomer population, pressures to control health spending and the availability of new technology to implement decentralized care."

Several companies have already developed remote sensing technology for health-care and lifestyle monitoring *(see "Clothed in Health,"* TR *July/August 2001)*. Most of these first-generation gadgets grab data on your vital signs and then radio the information back to a home health station or a receiver hooked to your PC. Now physicians and engineers at a handful of universities and startups are pushing the technology even farther. Their goal is to harness new materials and powerful microelectronics to make devices that are even more intelligent and self-contained—to make not only data reporters but preventive aids that detect dangerous medical conditions.

One leading group in the development of the technology is at the University of Rochester's Center for Future Health, which was founded in 1999 by Rochester engineer Philippe Fauchet and physician Alice Pentland, in collaboration with MIT's Media Laboratory. "Today, we wait until you get sick, drag yourself to the doctor, and then we throw this multimillion-dollar heroic technology at you," says Fauchet. "So we wondered if it was possible to do early detection, even before you got sick, with technology that is very inexpensive, consumer friendly, and doesn't require a complex change in lifestyle."

In addition to smart socks, the center is developing bandages that warn of the beginnings of an infection and even identify the responsible bacterium and the appropriate antibiotic needed to treat it. The bandages are made from either light-emitting polymers or luminescent porous silicon with microcavities that emit light. Areas of the materials bind to specific DNA sequences of different bacteria; the binding causes a detectable change in the light emitted from the polymers or the silicon cavities.

Not all the new home medical devices are meant to be worn—or stuck on your skin. "I don't think we'll have to wait more than three years to see devices that can be retrofitted into the home," predicts Reuben Mezrich of the Center for Innovative Minimally Invasive Therapy, a consortium that includes MIT and Massachusetts General Hospital.

MIT's Department of Architecture is working on a Home of the Future that will use a range of biometric sensors to track its occupants' daily habits. One objective is a system for detecting the early onset of congestive heart failure in those at risk for the disease, says researcher Stephen Intille. Via handheld computers, the system would periodically ask the occupant questions about how he or she is feeling, and combine the responses with sensor data—say, how often the person gets up and walks around—to determine if a crisis is imminent. "The goal is to acquire meaningful data from a person in a nonannoying way over long periods of time and use it to detect a trend towards congestive heart failure and alert the doctor," explains Intille.

These high-tech medical diagnostics have not escaped the notice of industry. Strategists at semiconductor maker Intel, for example, reckon there's a $5 billion market for microchips in such home health-care devices. Nobody expects that smart devices will replace the judgment of trained physicians, but the future of health care will almost certainly include a brainy silicon gadget right in your home.

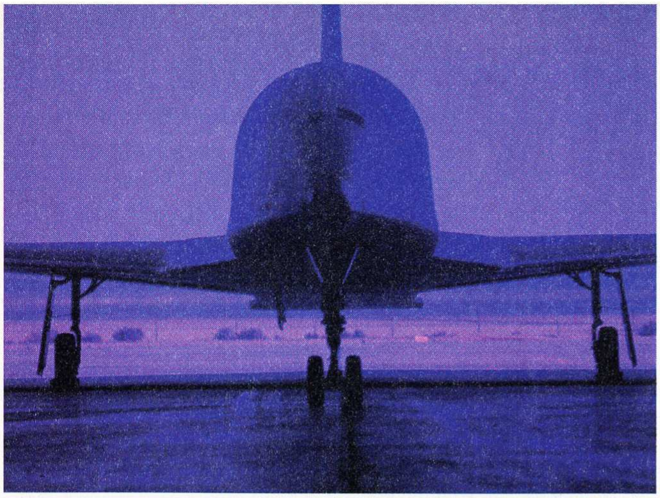
—David Voss

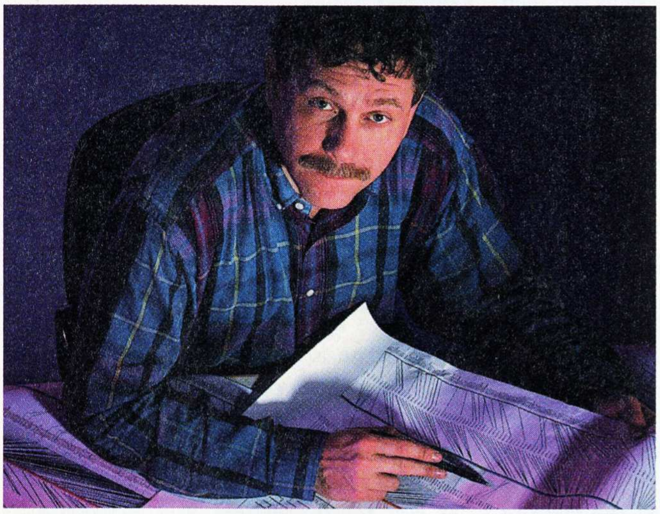
Device Sampler

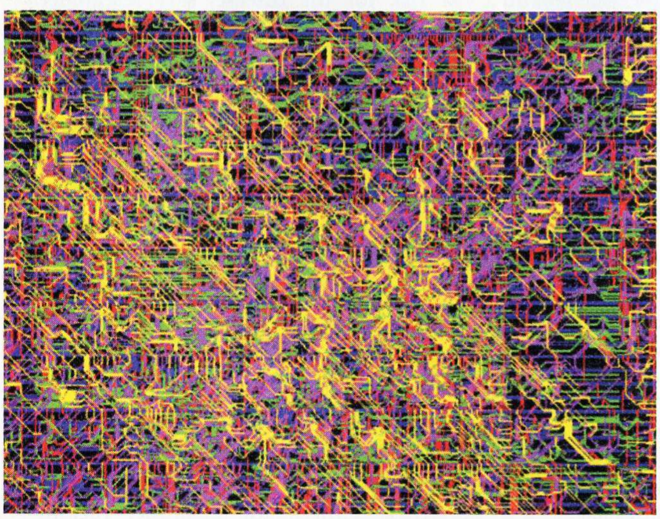
GROUP	PROJECT
University of Rochester Center for Future Health (Rochester, NY)/ MIT Media Laboratory (Cambridge, MA)	Smart socks for diabetics, to detect circulation problems; smart bandages to detect bacteria; digital imaging to detect skin tumors
Georgia Tech (Atlanta, GA)/Sensatex	Smart Shirt: sensor-embedded fabric (Addison, TX)
Cygnus (Redwood City, CA)	Skin sensors for glucose monitoring
MIT Department of Architecture (Cambridge, MA)	Home of the Future: detection and tracking of occupant activity
Intel Architecture Labs (Hillsboro, OR)	Smart home for elder care: sensors embedded in home for health monitoring
Georgia Tech Broadband Institute	Aware Home Research Initiative: audiovisual sensors, wearable sensors and "smart floors"

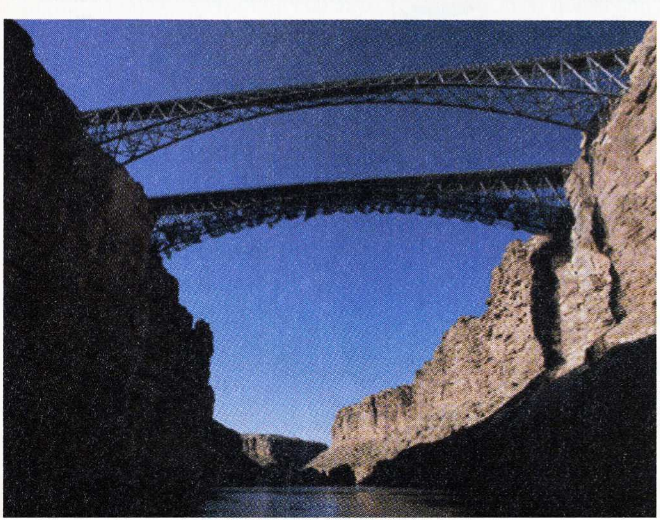
Georgia Tech's Smart Shirt

STANLEY LEARY, GEORGIA INSTITUTE OF TECHNOLOGY


ORBITAL SCIENCES


WHITEHEAD INSTITUTE


SIMPLEX SOLUTIONS


PHOTODISC

The Green-*back* Revolution

BONA FIDE OR NOT, CONCERNS about the safety of genetically modified crops have been grabbing headlines. But a far bigger story looms in agricultural biotechnology: that of an industry choking on its own patent claims. For a powerful example, consider recent patent activity at Monsanto.

First, the company won a patent—number 6,174,724 for those keeping score—that covers a seminal technology in transgenic plant research: the use of antibiotic-resistant genes as markers. It works like this: when researchers want to insert new genes into plant cells, say to create a drought-tolerant crop variety, they couple these ingoing genes with such a genetic marker. By then exposing the target cells to antibiotics to see if they die (they don't if things got to the right place), scientists can easily test whether the gene transfer was a success. There is probably no one in transgenic plant research who doesn't make use of this technique. But now, thanks to the U.S. Patent and Trademark Office's woeful ineptitude, they will all have to beg permission from Monsanto to use this fundamental technology, not to mention pay any royalties the firm sets.

Amazingly, however, an even worse intellectual-property nightmare is brewing. A pending Monsanto patent claims exclusive rights to a pivotal, widely used germ called *Agrobacterium tumefaciens*. This was the very first Trojan horse that scientists employed to sneak foreign genes into plants way back in 1983. And if Monsanto wins exclusive control over it, the field will be rocked even harder.

The real tragedy here is that both these patents (one granted, one pending) would confer monopolies on technologies that fall way too far upstream of the market to deserve patent protection. As many scholars have noted, patents are supposed to be a compact between the public and the inventor: in exchange for allowing the inventor a limited monopoly, the public gets access to a new product. But in these cases, there is no new product. Instead, Monsanto has essentially grabbed a piece of the ag biotech "infostructure"—claiming exclusive rights to a technological technique that everyone in the field needs to compete.

The problem is even worse in the *Agrobacterium* case. This patent was filed nearly two decades ago but has been tied up in a purgatory called "interference." With four competing research teams claiming to have invented essentially the same thing, the tortuous case has already taken a mind-numbing 18 years to adjudicate, with, not one, but two administrative-law judges retiring during the process!

Crazy biotech patents on the building blocks of science stifle innovation. Third World agriculture suffers most.

Thankfully, new rules will prevent the worst excesses of such situations by starting the clock ticking on a patent's life when an application is filed. But under the rules operating in this case (and all pre-1995 filings), the clock doesn't start until a patent is granted. Which means that Monsanto is poised to walk away with a spanking-new, 17-year monopoly on a technology that has long since become indispensable.

Which leads me to another gripe: the private capture of public investment. Several teams that developed this powerful technology included academic researchers operating partly on government grants. In a collegial spirit, these scientists freely passed valuable findings to Monsanto, which is now turning them into an exclusive claim.

The full story is chronicled with great insight by Daniel Charles in *Lords of the Harvest: Biotech, Big Money and the Future of Food*. The book has a lot more on its mind than *Agrobacterium tumefaciens*, as Charles examines the outsized ambitions that characterize the whole ag biotech industry. But to my eye, if Monsanto succeeds in patenting the use of this germ, it will go down as a classic tale of a collaborative scientific endeavor perverted by a capricious, winner-take-all patent system.

The problems extend far beyond two bad patents. In fact, so many overly broad patents have issued in agricultural biotechnology that the entire field will likely suffer. With tremendous consolidation in recent years, warring fiefdoms of technological know-how have emerged. Firms like Monsanto use their patents to squelch competitors and leverage control of technology in the pipeline. Researchers are becoming so hamstrung by proprietary claims to key conceptual tools—sometimes shut out from using them entirely—that it is becoming ever harder to bring new inventions to market.

This is bad enough in the commercial sector. But the tangle of exclusive claims on basic research is also smothering public-sector researchers who, just a generation ago, launched the Green Revolution to bring high-yield crop varieties to the famine-plagued developing world. That revolution was spawned not only by new technology but by a commitment to use new seed varieties as building blocks to breed even better varieties in the future. With proprietary claims like Monsanto's, we're tilling a far less fertile field. Maybe we should call it the Greenback Revolution. TR

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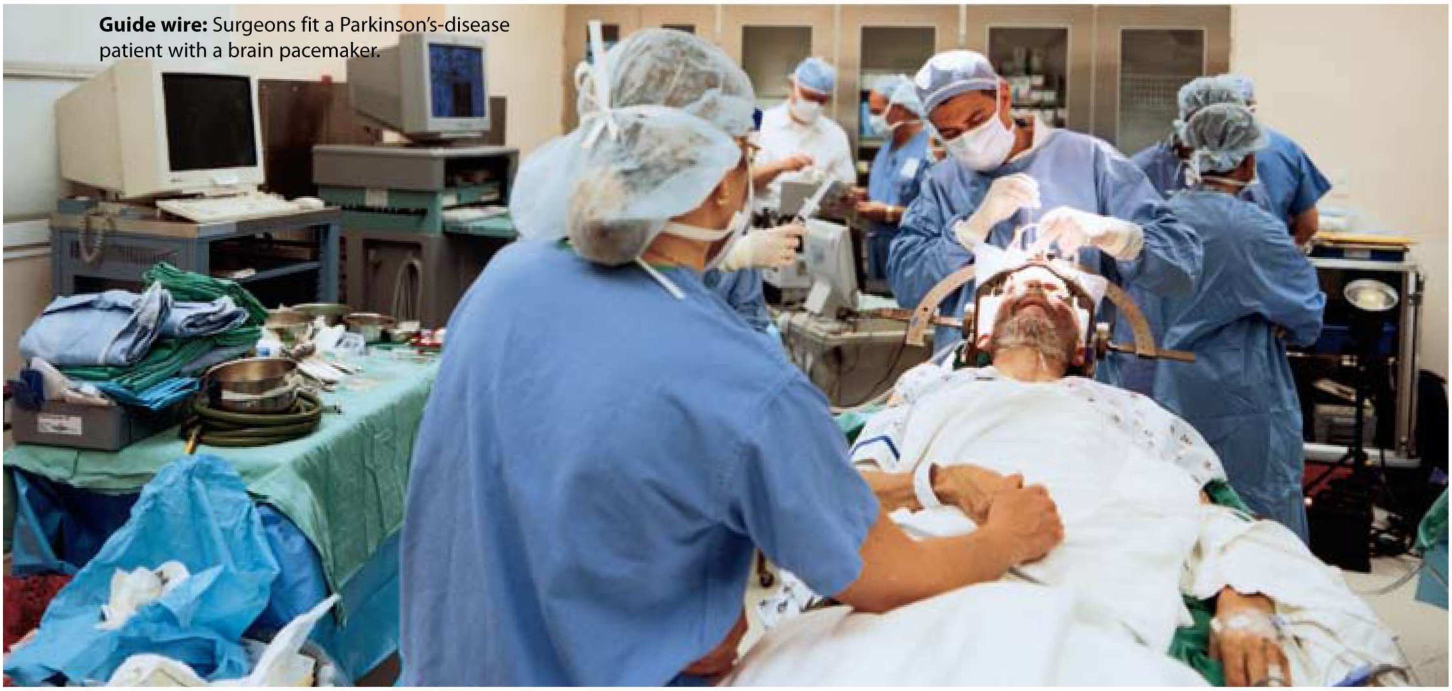
Surgeons are implanting tiny electrodes in the brains of patients suffering from everything from Parkinson's disease to obsessive-compulsive disorder. Soon, these devices may be as common as heart pacemakers.

By Stephen S. Hall

BRAIN PACEMAKERS

Photographs by Sian Kennedy



Guide wire: Surgeons fit a Parkinson's-disease patient with a brain pacemaker.

It had been more than six hours since Joan Sikkema first laid her shaven head on the operating table, six hours since a 14-millimeter hole was drilled in her skull and a thin electrode inserted deep inside her brain. Now, swaddled in blankets in the cold operating room and wide awake, Joan (pronounced joe-ann) looked up at half a dozen physicians in surgical gowns, all of whom seemed to be shouting orders at her simultaneously.

"Put your hands out steady!" one said.

"Touch your finger to your nose!"

"Puff out your cheeks!" said another. Pairs of eyes met over surgical masks, and half-nods were exchanged.

This was supposed to be the climactic moment of a surgical session that had begun around 9:00 a.m., when Ali R. Rezai, an Iranian-born and Western-trained neurosurgeon, opened the tiny porthole in the left side of Joan's skull, about five centimeters behind the hairline. Rezai and a team of functional neurosurgeons, neurologists and nurses at the Cleveland Clinic Foundation in Ohio had spent the next few hours electronically eavesdropping on single cells in Joan's brain, attempting to pinpoint the precise trouble spot that caused a persistent, uncontrollable tremor in her right hand. Once confident they had found the spot, the doctors had guided the electrode itself deep into her brain, into a small duchy of nerve cells within the thalamus. The hope was that when they sent an electrical current to the electrode, in a technique known as deep-brain stimulation, her tremor would diminish, and perhaps disappear altogether.

"Any tingling in the area?" asked neurologist Erwin B. Montgomery Jr., standing over Joan and tweaking the knob on a device that controls the voltage, frequency and duration of electrical stimulation. He was both testing the electrode's effectiveness and making sure it wasn't in a place where a burst of electricity could cause problems. Several millimeters too far back could cause a tingling sensation known as parathesis and possibly speech problems. Several millimeters too far forward, and the electrode might miss the target and have no therapeutic effect at all. Every question the doctors fired at Joan elicited a geographical answer about the exact position of the electrode inside her brain.

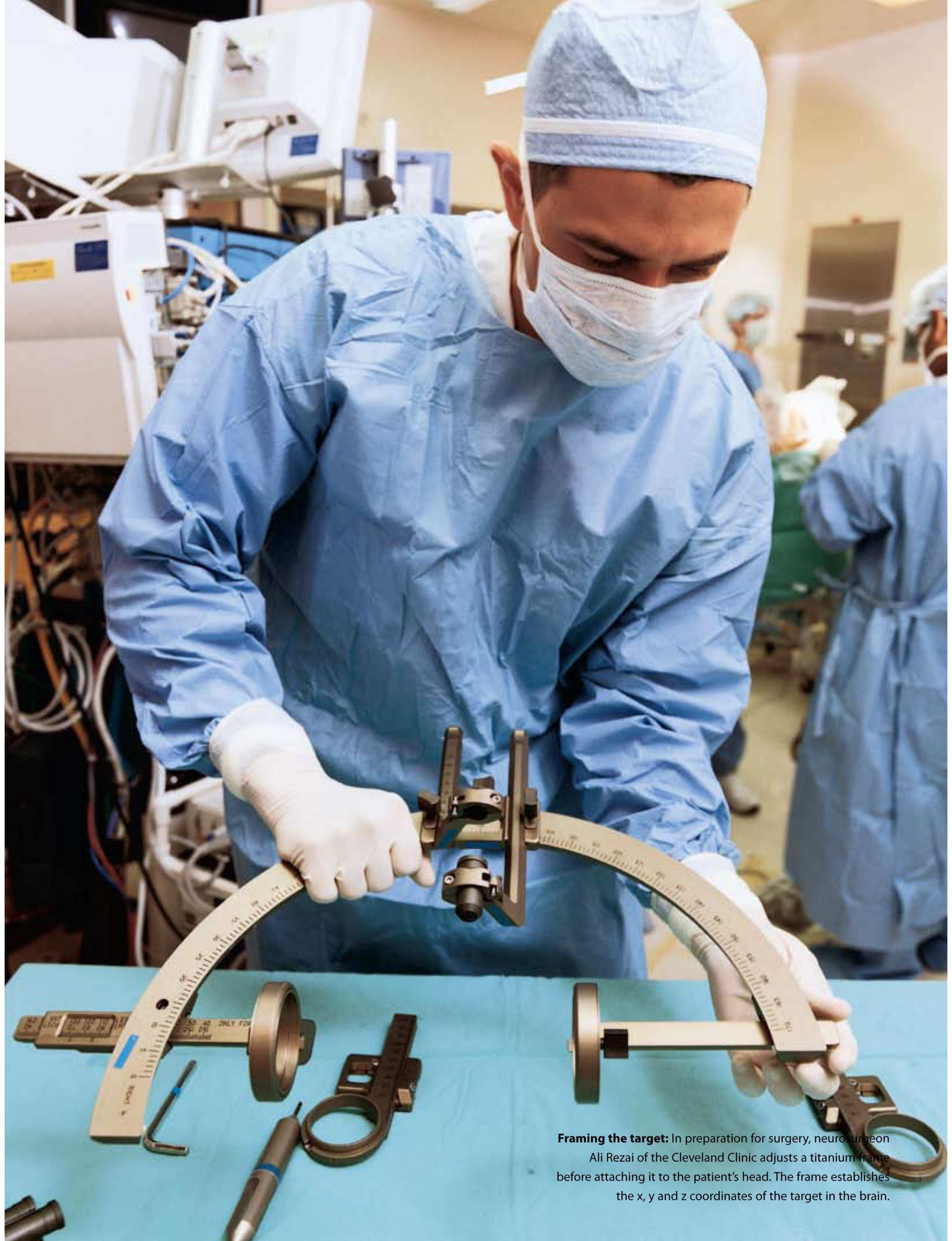
"Hold out your hands." Joan held her hands straight out. There was nary a tremor or shake. "Boy, that looks pretty steady," Montgomery announced. "Okay, open your mouth." Joan slowly opened her mouth. "Say, 'Today is a lovely day.'"

"Today…is…," Joan said, very slowly, "a…lovely…day."

If functional neurosurgeons like Rezai are correct, this collaborative medical scene, where patients lie awake in the operating room and help doctors implant a kind of neurological pacemaker, could soon be commonplace. Similar to heart pacemakers, which are surgically implanted in the chest and use electrical stimulation to maintain optimal cardiac rhythm, brain pacemakers consist of an electrode permanently implanted in the brain to maintain neural equilibrium. The electrode emits electric pulses from a power pack in the chest.

Brain pacemakers were first successfully implanted in humans nearly 15 years ago in France, and in 1997, the U.S. Food and Drug Administration approved the first U.S. use of pacemakers to treat essential tremor and Parkinsonian tremor—currently, the only approved indications. But until very recently, the procedure had been performed relatively infrequently, and not surprisingly, it has been viewed with great caution. "Historically, the field has been hindered—appropriately—by the problematic memory of things like the lobotomy, where the science wasn't there and many of the outcomes were horrific," says Joseph J. Fins, chief of the Division of Medical Ethics at Weill Medical College of Cornell University.

But now, as the science of brain circuitry has become better understood, and as the long-term outcomes of brain pace-



Framing the target: In preparation for surgery, neurosurgeon Ali Rezai of the Cleveland Clinic adjusts a titanium frame before attaching it to the patient's head. The frame establishes the x, y and z coordinates of the target in the brain.

makers have shown the technology to be both effective and safe, that could be about to change. The FDA is now considering—or soon will be asked to consider—several applications that could ultimately open up the technology to tens of thousands of patients with disabling neurological conditions. For instance, the FDA was expected this summer to approve the use of brain pacemakers for the treatment of a number of other Parkinson's-related symptoms, such as stiffness. The agency recently authorized investigational use of the devices to treat certain forms of epilepsy and approved testing of pacemakers in the treatment of obsessive-compulsive disorder; the first three patients with obsessive-compulsive disorder received implants earlier this year at Butler Hospital in Providence, RI. Within a year, surgeons at the Cleveland Clinic expect to test the devices as a treatment for severe depression. And by the end of this year, the group hopes to begin using deep-brain electrical stimulation to try and "awaken" patients who have suffered severe brain damage and live in a cognitive limbo known as a "minimally conscious state." In the more distant future, laboratory research suggests that pacemakers may even have a role in controlling behavioral disorders, such as obesity, anorexia and addiction.

Doctors estimate that brain and neurological conditions afflict more than 50 million Americans. "For all these conditions, conservative therapy like drugs helps, but basically 10 to 20 percent of patients are refractory to these therapies," says Rezai. "Surgery is not for everybody. At this point, we really have to reserve it for end-stage patients for whom nothing else works. But that's evolving. I equate it to where heart pacemakers were in the 1950s. Back then, you would tell someone, 'I'm having a pacemaker put in,' and people would go, 'What's that?' Now everyone knows what a heart pacemaker is. I think that it will be a similar situation for brain pacemakers in 10 or 20 years."

The recent operation on Joan Sikkema at the Cleveland Clinic may well be a harbinger of this coming revolution in brain surgery. But like any new medical procedure, it wasn't without its worrisome moments. Six hours in, the slowness of Joan's speech began to sound like something other than weariness. The words were mushy and slurred. Someone asked Joan how she felt, and she mumbled a reply that, although hard to hear, didn't sound cheerful.

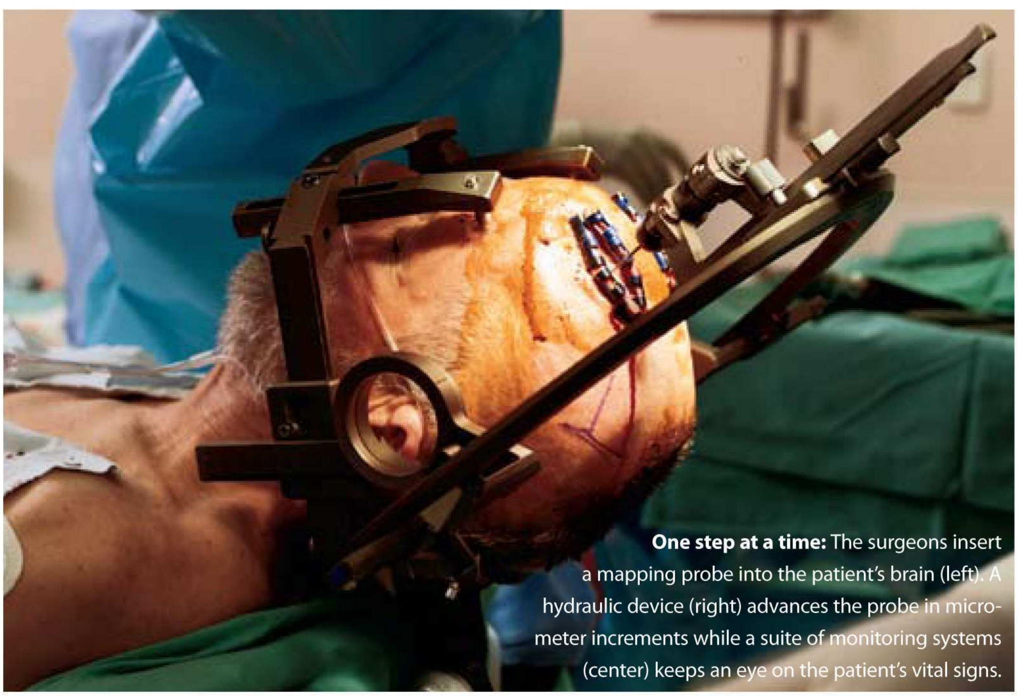
"What did she say?" someone asked. "What did she say?" The neurosurgeons were aiming for a target roughly the size of the eraser on a pencil, and clearly they weren't there yet.

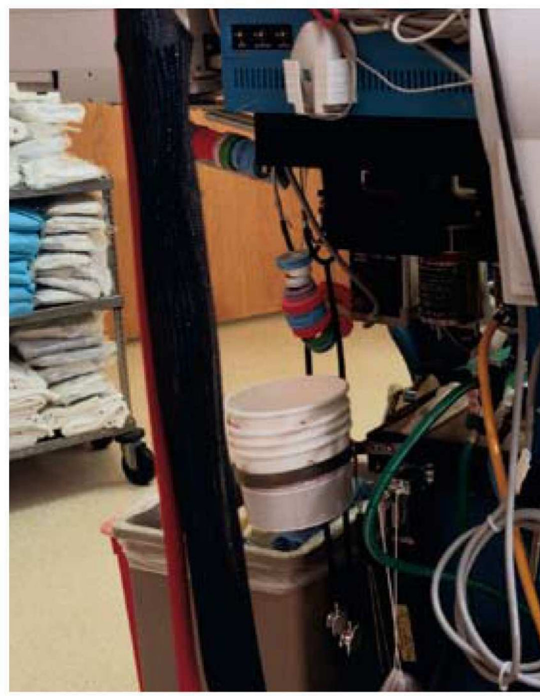
Jump-Start

Humans have been using electric current as a therapeutic agent at least since the Romans employed the Mediterranean torpedo—a kind of stingray that discharged electricity—in treating, presumably, gout and pain in the lower extremities. Electroconvulsive or shock therapy has been used for decades, predominantly as a treatment for severe depression. Nor is electrical stimulation of the brain, strictly speaking, new. The first recorded attempt occurred in 1874, when a doctor in Ohio inserted a needle into the brain of a patient with cancer and applied electricity. In 1948, J. Lawrence Pool of Columbia University tried using electrical stimulation against depression.

By the mid-20th century, electrical stimulation of the brain fell mostly into disuse—in part because of the rise of neuropharmacology, and in part because of a social and ethical hangover from the first, swashbuckling era of psychosurgery. Indeed, the recent evolution and practice of elective neurosurgery, especially for the treatment of psychiatric disorders, has been haunted by the chilling history of the lobotomy. The severing of nerve connections in the prefrontal cortex was first attempted in 1935 by a Portuguese neurologist, António Egas Moniz. The procedure was popularized in this country by Walter J. Freeman in Washington, DC, and commonly used as a treatment for depression until the late 1950s.

Despite the horrific consequences of this crude form of neurosurgery, there was a kernel of scientific merit to lobotomies. Freeman believed the operations disrupted neural connections





One step at a time: The surgeons insert a mapping probe into the patient's brain (left). A hydraulic device (right) advances the probe in micrometer increments while a suite of monitoring systems (center) keeps an eye on the patient's vital signs.

between the frontal cortex of the brain and the thalamus, which consists of two walnut-sized structures deep in the brain, one in each hemisphere, each composed of 120 distinct neural clusters, or nuclei. The thalamus influences not only emotion but things like movement and sensation, and it is clusters of neural tissue in and around the thalamus that neurosurgeons are now revisiting—not with knives or ice-picks, but with electrodes.

The renaissance in deep-brain stimulation began, serendipitously, toward the end of 1985, in an operating room in France. At the University of Grenoble, neurosurgeon Alim-Louis Benabid was preparing to ablate, or destroy, a portion of the thalamus in a patient whose hand flapped uncontrollably with the condition known as essential tremor. This drastic form of surgery, involving heat or radiation, is typically the last therapeutic option for patients with motor disorders who have exhausted all other treatments. "Before making a lesion on the target," Benabid says, "you must make sure you are not in a place where the lesion would be inappropriate and cause a permanent deficit." The way to determine the location, then and now, is to send a short burst of electricity through an electrode and observe the effect. In this case, the effect stunned everyone in the operating room, including the patient.

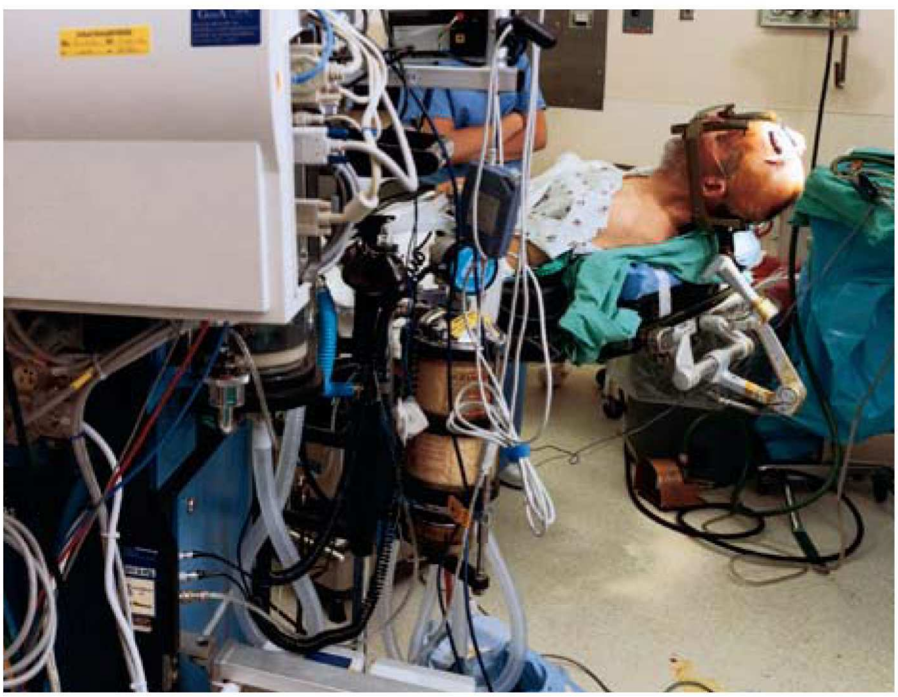
"What I saw," Benabid recalls, "was that his hand stopped flapping. I turned off the stimulation, and the tremor came back. So I apologized to the patient and said, 'That was unfortunate. Was it painful?' And the patient said, 'No, no, it was nice. Can I try it again?' So we tried again, and the tremor stopped. My first thought was, I was relieved that it wasn't a complication. The concomitant thought was, 'That's interesting!'"

Armed with this intriguing chance observation, Benabid jerry-rigged some existing electrical stimulation equipment to attempt deep-brain stimulation experimentally. The first opportunity presented itself in 1987, with a Parkinson's patient who had already undergone the surgical destruction of the thalamus on one side of the brain. The patient had developed a tremor on the other side, but destroying thalamic tissue on both sides of the brain is exceedingly undesirable, so Benabid offered to implant an electrode instead as a last-gap measure. The patient agreed, and thus began the modern era of deep-brain stimulation.

Nearly 15 years later, the technology has become much more refined. The Grenoble group has reported on the largest group of patients to date; in 148 Parkinson's-disease patients treated since 1993, the average rate of improvement, measured according to a traditional scale used to assess Parkinson's symptoms, was 65 percent. And the benefits have not diminished.

"We're at the cusp of a new era in terms of therapy," says Montgomery, who with Rezai codirects the Center for Functional and Restorative Neuroscience at the Cleveland Clinic. "Up to now, the field has been dominated by pharmacology. But deep-brain stimulation is going to have a tremendous impact on neurology. Basically, the brain is an electrical device, so it stands to reason that we should be able to influence the brain electrically. And we can offer a specificity and precision that drugs will never be capable of."

Brain pacemakers also offer significant advantages over traditional neurosurgery, in which, Rezai says, portions of the deep brain are irreversibly destroyed. Implanting electrodes, while minimally invasive, does not destroy chunks of tissue. "In this day and age," Rezai says, "there's no reason to have destructive brain surgery. It's a one-shot deal and you can have side effects that are permanent. With stimulation, you can turn it off and you're back to where you started, so it's fully reversible. And you can adjust it, tailor the device to the patient's needs."

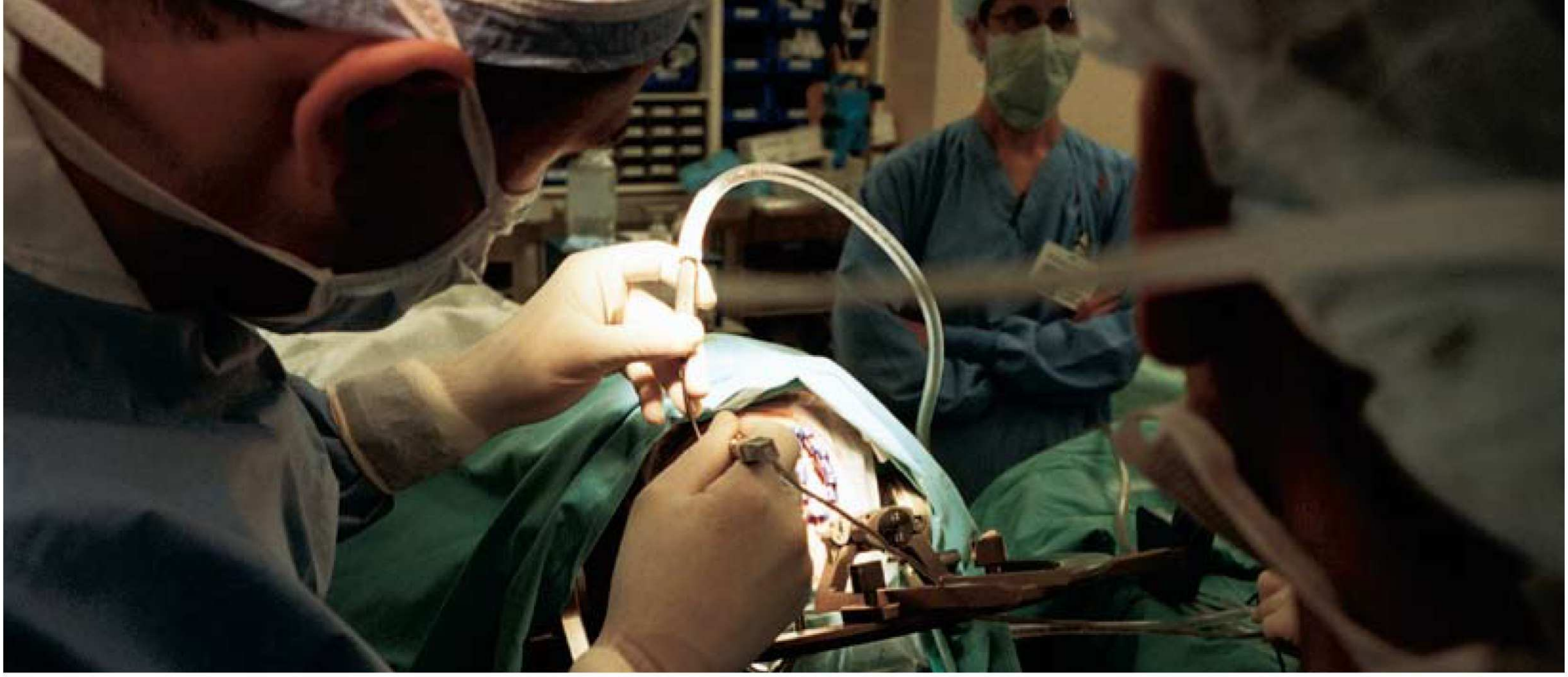


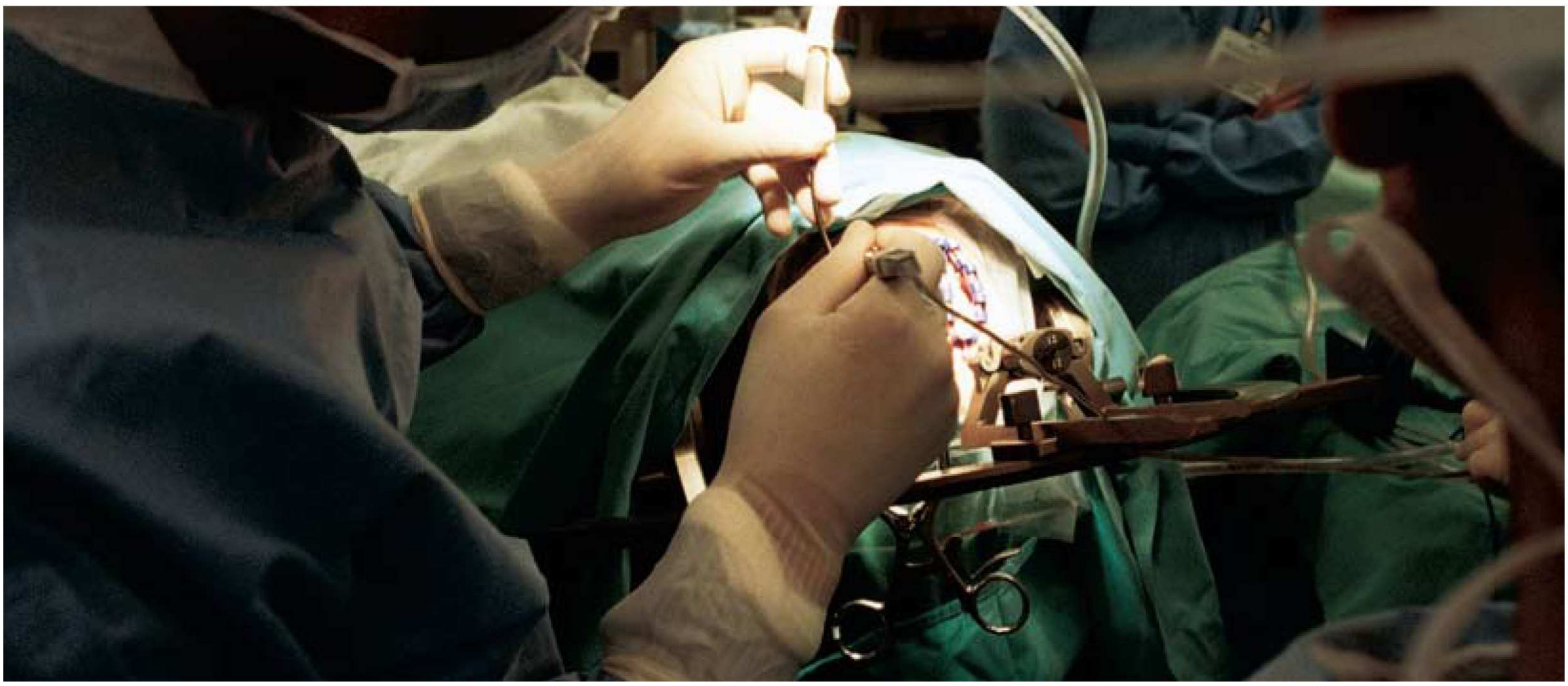
Electric Cartography

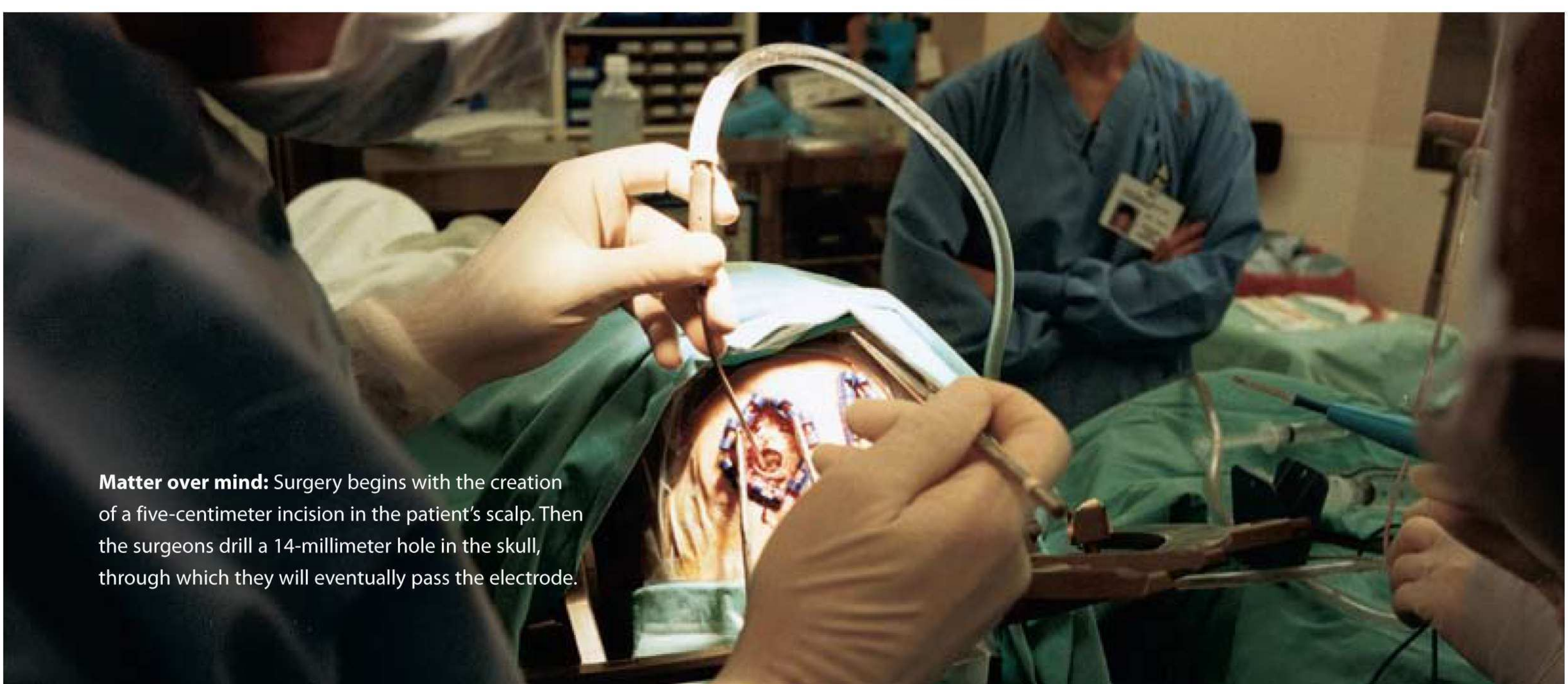
"We're going to attach your head to this bed, okay?" said Rezai, positioning Joan on the operating table.

"Do I have a choice?" she answered with a laugh.

Opting for invasive brain surgery may seem like a dire solution for shaky hands and compulsive thoughts, but patients with serious neurological ailments are often eager to try it. The day before her doctors implanted her pacemaker, Joan described the







Matter over mind: Surgery begins with the creation of a five-centimeter incision in the patient's scalp. Then the surgeons drill a 14-millimeter hole in the skull, through which they will eventually pass the electrode.

trauma of daily life with a condition like essential tremor. Wearing a pink blouse, khaki slacks and sandals, the 52-year-old woman from Byron Center, MI, looked like the youthful, good-natured grandmother that she is. But her hands shook uncontrollably. She rattled off a list of quotidian frustrations that helps explain why patients are willing to let doctors drill holes in their heads and stick electrodes into their brains.

Here are some of the things she could not do: Eat soup (she needed two hands). Put on makeup. Brush her teeth. Dial the phone (she often got wrong numbers). Tie her shoes. Hold her grandchildren. "I used to be a nurse," she explained, her voice itself a little shaky, "but I had to give it up because of the tremor—you know, giving injections, changing dressings, writing in charts. People like to be able to read the chart," she added with a laugh, "and my handwriting was worse than a doctor's." She held an imaginary pen in her right hand, and it carved wild elliptical arcs in the air, as if she were shaking a thermometer.

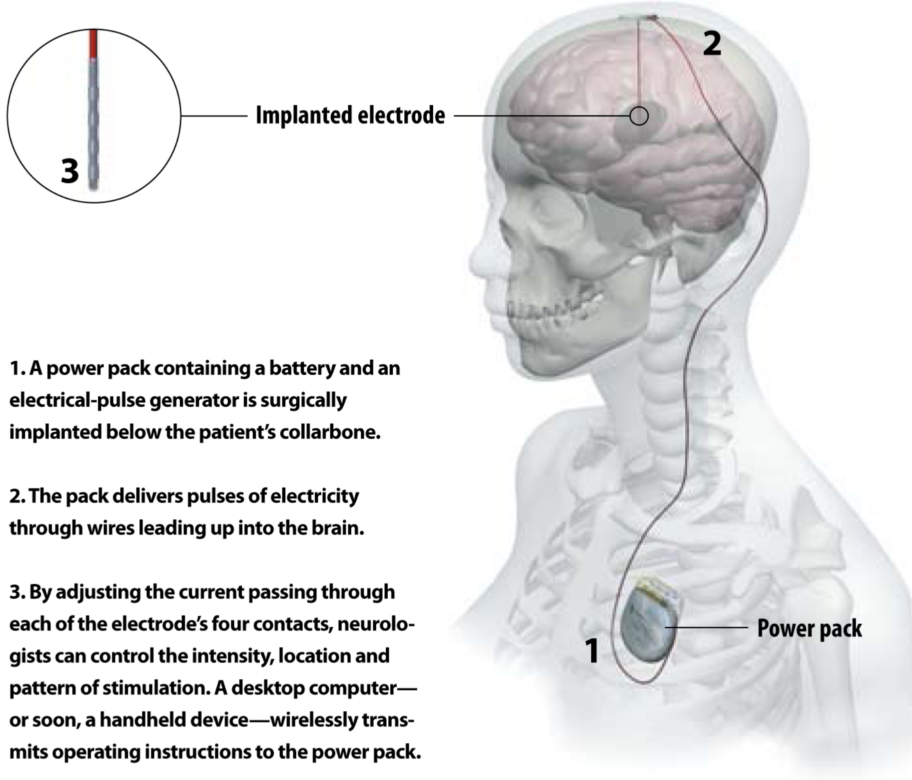
Like many people with a severe movement disorder, Joan found that drugs were not effective, and the symptoms grew worse over time. On the eve of having her pacemaker implanted, she did not seem unnerved by the prospect of brain surgery—even when Rezai recited possible complications, including a chance of infection and a one to two percent chance of bleeding in the brain. "Going to a dentist," she said with a tight smile, "is more traumatic for me than this."

The procedure, needless to say, is a little more complicated than a root canal. Implanting electrodes deep in the brain combines the latest in imaging and stimulation technology with, paradoxically, a slow, painstaking, hands-on mapping of each patient's neural terrain during surgery. This kind of cartography is essential, Rezai explains, because the geography of each human brain is different. The lay of this precious land must be custom-mapped by the surgical team, so that when the actual electrode is maneuvered into place, it will provide optimal therapeutic results while minimizing possible side effects.

Like all maps, this one begins to take shape with the establishment of coordinates. With a titanium frame attached to her head, Joan underwent a computed tomography scan before being wheeled into the operating room. Rezai then used a software program to merge the results of that scan, a magnetic resonance imaging scan taken the previous day, and a computerized standard brain atlas to create a 3-D image of Joan's brain. Within that image, Rezai identified the x, y and z coordinates of the target for the electrode he would implant. Having selected a trajectory that avoided blood vessels, fluid-filled structures and other critical neural regions, Rezai's team began the process of actually exploring a route to the trouble spot, advancing the preliminary probe about six centimeters into the brain. Once they were within about 15 millimeters of the thalamus, they used a hydraulic device to advance the probe in micrometer increments, and the vast portion of the day was spent traversing a distance smaller than the diameter of a dime.

This was done as much by sound as by visualization. The probe, sensitive enough to pick up electrical signals from a single cell, was wired to a laptop computer and amplifier. As one doctor moved it deeper into the brain, the operating room began to fill with the ebb and flow of brain cells firing, talking, reacting; the doctors, meanwhile, stood around with furrowed brows, trying to discern neural nuances in the amplified static. "You can think of the different thalamic nuclei as separate countries," Rezai explains. "Each country

Anatomy of a Pacemaker



1. A power pack containing a battery and an electrical-pulse generator is surgically implanted below the patient's collarbone.

2. The pack delivers pulses of electricity through wires leading up into the brain.

3. By adjusting the current passing through each of the electrode's four contacts, neurologists can control the intensity, location and pattern of stimulation. A desktop computer—or soon, a handheld device—wirelessly transmits operating instructions to the power pack.

ILLUSTRATION BY JOHN MACNEILL

Brain Pacemaker Clinical Trials

Deep-brain stimulation is being tested to treat an array of disorders

DISORDER	START DATE	RESEARCH GROUP
Epilepsy	1998	Stanford University; University of Pennsylvania; Johns Hopkins University; Emory University;
	Toronto Western Hospital	
	2000	University of Grenoble, France; Cleveland Clinic
Obsessive-compulsive disorder	1998	Catholic University, Belgium
	2001	Brown University; Cleveland Clinic
Depression	End of 2001	Toronto Western Hospital; Cleveland Clinic
Minimally conscious state	End of 2001	Cleveland Clinic (with Weill Cornell Medical Center)

speaks a different language, and we can recognize the language of different cells."

As the probe neared the thalamus, the surgical team stopped every time it encountered the telltale rat-a-tat of a firing cell. "We're getting close to one there…," Rezai said, head tilted as if he were listening to a faraway cricket. The crackle grew louder and louder, sounding like heavy rain on a tin roof, or distant gunfire. "We're in the thalamus now," he announced.

Every once in a while, the amplifier would spit out a distinctly different sound—a kind of pop or sudden "pfftttt." "That zip you hear?" Rezai explained. "That's an injury current," the sound of a neuron pierced by the probe (it's unclear if the cells repair themselves, Rezai says, but the damage is considered minimal). The surgeons inserted the probe three times, using slightly different trajectories, to pinpoint the pencil-eraser-sized target of brain tissue.

Five and a half hours into the surgery, satisfied that they had found the right spot in the thalamus, Rezai and his team were ready to insert the permanent electrode *(see "Anatomy of a Pacemaker," p. 41)*. After guiding it into place, the surgeons prepared to test the device. "Okay, Joan," Rezai said, "I want you to give us your maximum tremor." She had a hard time doing it, however, because the mere placement of the electrode seemed to dampen her shakiness. "That's a good sign," Rezai said.

Why stimulation should even work, actually, is a nagging scientific question. Standing by the electrode's voltage controller, Erwin Montgomery paid tribute to the fundamental mystery underlying this entire field of surgery. "The $64,000 question is: how the heck does deep-brain stimulation have its effects? Nobody knows the answer."

Brain GPS: Computer brain images (opposite left) and recordings of neurons firing (opposite right) help guide the surgeons as they implant the electrode. Once it is in place, they test its effectiveness (below).

Charging Ahead

As even its most enthusiastic practitioners concede, deep-brain stimulation in its current state is still relatively crude. But the future of brain pacemakers—greater sophistication and miniaturization, broader application—is unfolding at a rapid pace. "This is just the tip of the iceberg," says Hans O. Lüders, chairman of neurology at the Cleveland Clinic. Patients with epilepsy, he points out, are usually treated with antiseizure medication and, failing that, with a radical form of elective surgery to remove the part of the brain that becomes hyperactive during repeated attacks. More than two million Americans suffer from epilepsy, and roughly half of them have seizures that originate in the same region of the brain again and again. "At least 20 or 30 percent of these patients cannot be controlled with drugs," Lüders says. "What to do with them? This is where deep-brain stimulation comes in."

During the past year, the Cleveland group has implanted brain pacemakers in five epilepsy patients: two of the five have shown significant improvement, according to Lüders. And the prognosis may soon get even better with new pacemaker technologies. The next generation of stimulation devices will be the so-called closed-loop pacemakers, electrodes designed to both monitor brain electrical activity and deliver stimulation when necessary—rather than provide continuous electrical pulses. Already, a large, external version of this pacemaker has been tested in eight patients at the University of Kansas Medical Center with "excellent results," according to Ivan Osorio, who heads the research effort. And several groups are working with Minneapolis, MN-based Medtronic, currently the only company marketing these pacemakers, to develop a miniaturized version that could be incorporated into a chip. The strategy is to take advantage of the fact that epileptic seizures are often preceded by an electrical overture, or "aura," that warns of the coming neural storm minutes before the actual symptoms appear. "You sense what is going on in the brain, and you stimulate only when an epileptic seizure is coming on," Lüders explains.

The power packs used in brain pacemakers are also evolving. Currently, the packs are about the size of a pager and are implanted just below the collarbone—surgery that includes a painful procedure to hook up the pacemaker's power supply to the electrode. The bioengineering group at Cleveland Clinic is working with Medtronic to miniaturize the power packs to about the size of a quarter, which could potentially allow surgeons to implant the devices behind a patient's ear.

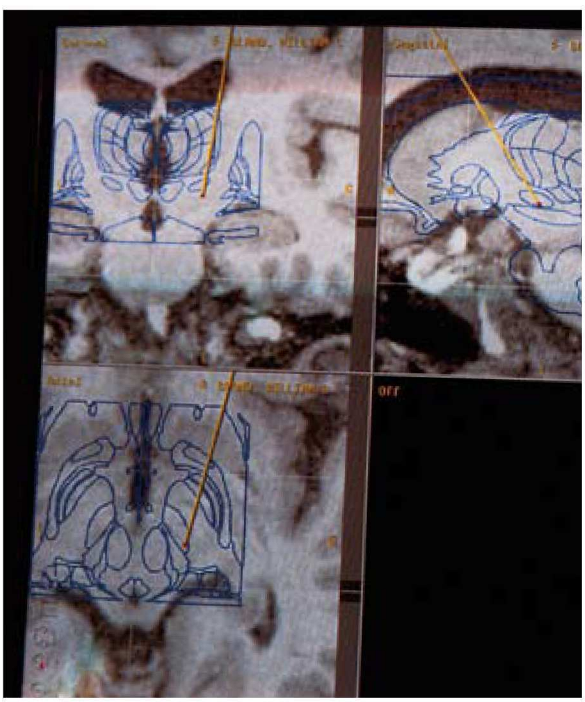
The catalogue of diseases targeted for electronic stimulation is evolving as rapidly as the technology. Obsessive-compulsive disorder, for example, is just now becoming a candidate for the treatment. In 1999, Bart J. Nuttin, a doctor at Catholic University in Leuven, Belgium, reported in *The Lancet* on the use of brain pacemakers to treat four patients with the disorder who were resistant to any other therapy; three of the four patients benefited from the new therapy. A 39-year-old woman who had suffered severe symptoms for more than two decades, for instance, experienced "an almost instantaneous feeling of being relieved of anxiety and obsessive thinking" when the electrode stimulator was turned on.

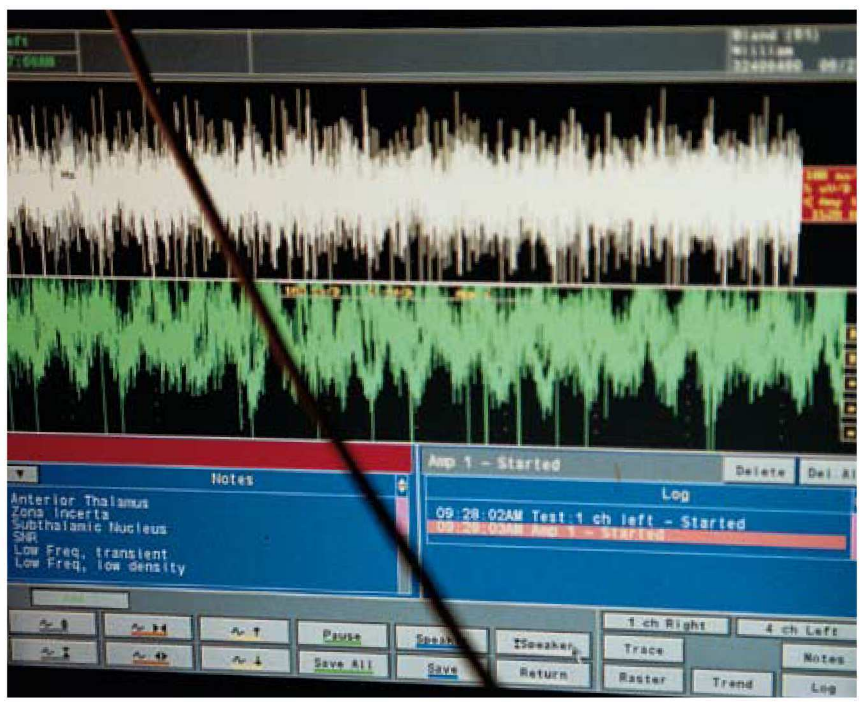
It won't be long before severe depression, too, may be experimentally treated with deep-brain electrical stimulation. Studies have shown that stimulation of the subthalamic nucleus has a significant impact on mood, says Cleveland Clinic's Montgomery, "and that might translate into therapy for depression."

Among the most daring potential applications of the technology is the use of electrical stimulation to improve the condi-

tion of patients with severe brain injuries. An estimated 5.3 million Americans are currently living with disabilities as a result of brain injuries, and a significant number of them are in minimally conscious states. Nicholas D. Schiff and Fred Plum of Weill Medical College in New York are developing diagnostic tools to identify brain-injured patients who retain some capacity for coordinated neural activity; such patients, they argue, might benefit from deep-brain stimulation. "We're not talking about people in comas, and we're not talking about people in semi-vegetative states," Schiff says. But brain-imaging technologies indicate that some patients have states of awareness that fluctuate. "It's just a matter of, 'Can you identify patients that have some cognitive states that are better than others and use deep-brain stimulation to push them into this better state?' In the next year or so, we might be able to pilot this therapy."

The University of Grenoble's Benabid has even shown—in rats, for the time being—that eating behaviors can be affected by brain pacemakers. High-frequency stimulation of the hypothalamus, another deep-brain structure, seems to spur appetite, and thus could be used as a last-resort treatment for severe anorexia nervosa; low-frequency stimulation seems to decrease appetite, and could be used to treat what he calls "malignant obesity." But Benabid, for one, is in no hurry to rush into behavior modification using brain pacemakers. "We have to be very cautious about this," he says. "You mention obesity, and people say, 'Wow, that's a big market here!' I don't like to hear 'big market.' We think we could provide some patients with a solution for something when nothing else is available. The danger is that the easier the procedures become—less invasive, less morbidity—the more tempting they are."





Restored Hope

Toward the end of her very long day in the operating room, Joan Sikkema lay on the table while Erwin Montgomery, the neurologist, stood beside her, adjusting the voltage of her stimulator. This was just a preliminary "tuning," giving her doctors a sense of how they might ultimately program her pacemaker several weeks later, when swelling from the procedure had subsided and the device could be turned on. But when Montgomery pushed up the voltage, Joan squirmed in discomfort. When Montgomery asked, "How does that feel?" she mumbled out a barely audible answer.

"What did she say?" the doctors asked.

Montgomery lowered his head to Joan's: "That was really crappy," she remembers whispering.

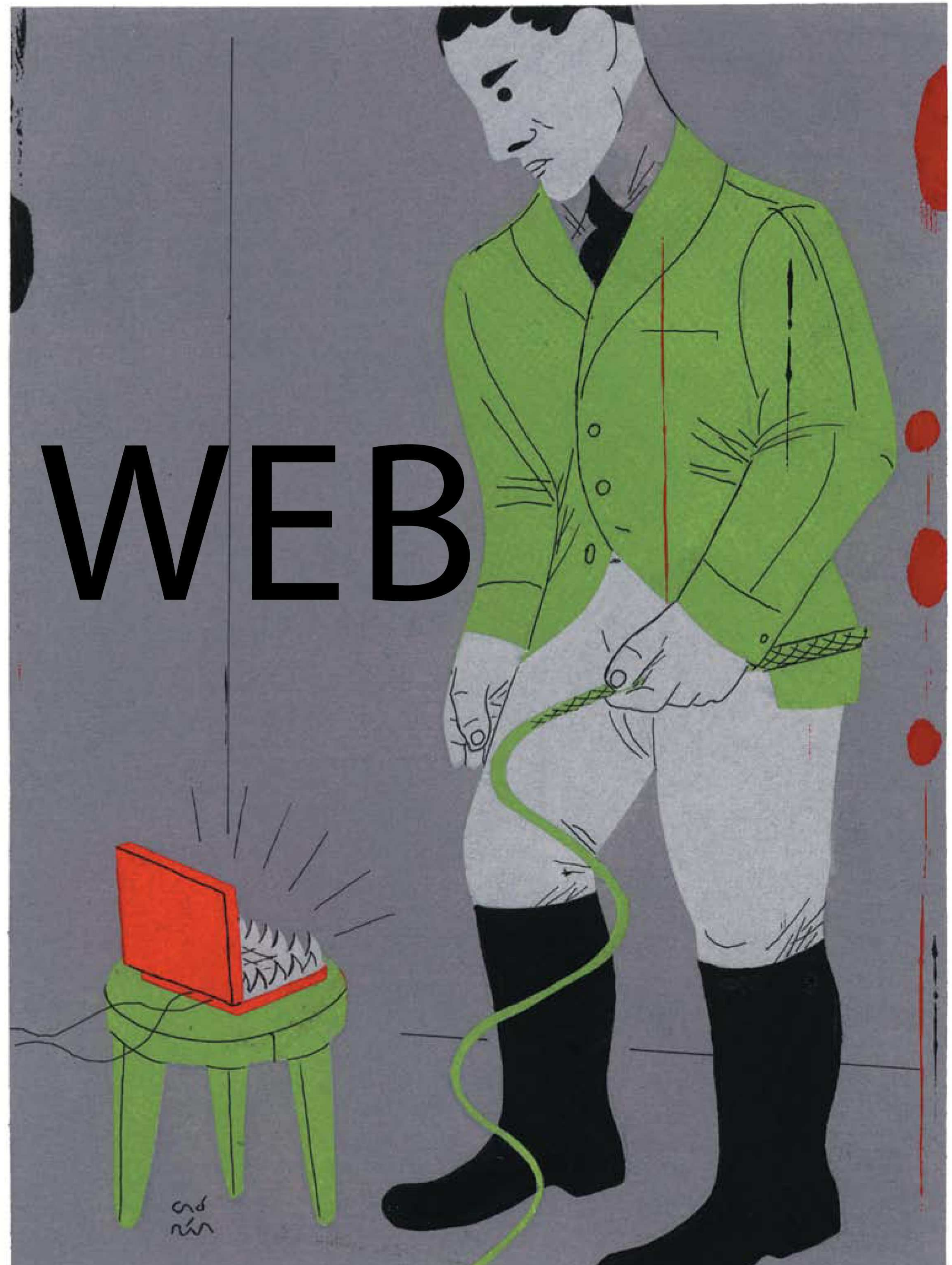
As the voltage increased, the stimulation had caused numbness in her mouth and throat, with obvious effects on her speech. Joan's case turned out to be challenging. Her thalamus was very "speech-dominant," Rezai said later; the doctors had to be careful about locating the electrode in a way that would control her tremor but not cause slurring or other speech deficits.

Several weeks after the surgery, Joan returned to Cleveland to get "turned on." She noticed a slight reduction of her symptoms, "but nothing dramatic." In fact, she even experienced some disquieting side effects and turned the device off (patients are given a magnetic device to shut off the pacemaker). But a week later, after the doctors had readjusted the settings of her pacemaker, she could barely contain her enthusiasm. "This time I was able to write my name, and feed myself without hitting my cheek, and drink from a cup without spilling it," she says. "I'm doing all the ordinary daily things I used to do."

It will take another five or six months, her doctors in Cleveland say, to get her pacemaker tuned optimally. Montgomery says that, following her second tune-up, tests showed Joan had 80 to 90 percent improvement in her intentional tremor, and 100 percent resolution of her postural tremor. But there is no quantitative instrument to measure the joy in her voice as she related her feelings after the last tune-up. "I didn't cry until this morning," she says, her voice tremulous with emotion, not neural dysfunction. "I think I was steeling myself in case it didn't work. But I got much more than I expected. It's like getting my life back." TR

BY CHARLES C. MANN
ILLUSTRATIONS BY BRIAN CRONIN

TAMING THE WEB



L December, Vincent Falco, a 28-year-old game programmer in West Palm Beach, FL, released version 1.0 of a pet project he called BearShare. BearShare is decentralized file-sharing software—that is, it allows thousands of Internet users to search each other's hard drives for files and exchange them without any supervision or monitoring. Released free of charge, downloaded millions of times, BearShare is a raspberry in the face of the music, film and publishing industries: six months after the release of version 1.0, tens of thousands of songs, movies, videos and texts were coursing through the network every day. Because the software links together a constantly changing, ad hoc collection of users, Falco says, "there's no central point for the industries to attack." BearShare, in other words, is unstoppable.

"Information wants to be free." "The Internet can't be controlled." We've heard it so often that we sometimes take for granted that it's true. But THE INTERNET CAN BE CONTROLLED, and those who argue otherwise are hastening the day when it will be controlled too much, by the wrong people, and for the wrong reasons.

Which, to Falco's way of thinking, is entirely unsurprising—almost a matter of course. BearShare is just one more example, in his view, of the way that digital technology inevitably sweeps aside any attempt to regulate information. "You can't stop people from putting stuff on the Net," Falco says. "And once something is on the Net you can't stop it from spreading everywhere."

The Internet is unstoppable! The flow of data can never be blocked! These libertarian claims, exemplified by software like BearShare, have become dogma to a surprisingly large number of Internet users. Governments and corporations may try to rein in digital technology, these people say, but it simply will never happen because…*information wants to be free.* Because, in a phrase attributed to Internet activist John Gilmore, *the Net treats censorship as damage and routes around it.* Laws, police, governments and corporations—all are helpless before the continually changing, endlessly branching, infinitely long river of data that is the Net.

To the generations nurtured on *1984*, Cointelpro and *The Matrix*, the image of a global free-thought zone where people will always be able to say and do what they like has obvious emotional appeal. Little wonder that the

notion of the Net's inherent uncontrollability has migrated to the mainstream media from the cyberpunk novels and techno-anarchist screeds where it was first articulated in the late 1980s. A leitmotif in the discussion of the Napster case, for example, was the claim that it was futile for the recording industry to sue the file-swapping company because an even more troublesome file-swapping system would inevitably emerge. And the rapid appearance of BearShare—along with LimeWire, Audiogalaxy, Aimster and a plethora of other file-swapping programs—seemed to bear this out.

Nonetheless, the claim that the Internet is ungovernable by its nature is more of a hope than a fact. It rests on three widely accepted beliefs, each of which has become dogma to webheads. First, the Net is said to be *too international* to oversee: there will always be some place where people can set up a server and distribute whatever they want. Second, the Net is *too interconnected* to fence in: if a single person has something, he or she can instantly make it available to millions of others. Third, the Net is *too full of hackers*: any effort at control will invariably be circumvented by the world's army of amateur tinkerers, who will then spread the workaround everywhere.

Unfortunately, current evidence suggests that two of the three arguments for the Net's uncontrollability are simply wrong; the third, though likely to be correct, is likely to be irrelevant. In consequence, the world may well be on the path to a more orderly electronic future—one in which the Internet can and will be controlled. If so, the important question is not whether the Net can be regulated and monitored, but how and by whom.

The potential consequences are enormous. Soon, it is widely believed, the Internet will become a universal library/movie theater/voting booth/shopping mall/newspaper/museum/concert hall—a 21st-century version of the ancient Greek agora, the commons where all the commercial, political and cultural functions of a democratic society took place. By insisting that digital technology is ineluctably beyond the reach of authority, Falco and others like him are inadvertently making it far more likely that the rules of operation of the worldwide intellectual commons that is the Internet will be established not through the messy but open processes of democracy but by private negotiations among large corporations. To think this prospect dismaying, one doesn't need to be a fan of BearShare.

MYTH #1: THE INTERNET IS TOO INTERNATIONAL TO BE CONTROLLED

At first glance, Swaptor seems like something out of a cyberpunk novel. A secretive music-swapping service much like Napster, it seems specifically designed to avoid attacks from the record labels. The company is headquartered in the Caribbean island nation of St. Kitts and Nevis. Its founders are deliberately anonymous to the public; its sole address is a post-office box in the small town of Charlestown, Nevis. Swaptor's creators seem confident that the company can survive beyond national laws—after all, the Internet is too spread across the world to control, right?

Indeed, Swaptor does seem protected. Nevis, according to company representative John Simpson, "has excellent corporate laws for conducting international business." He is apparently referring to the happy fact that Nevis has not ratified either the World Intellectual Property Organization Copyright Treaty or the WIPO Performances and Phonograms Treaty, both of which extend international copyright rules to the Internet. As a result, Swaptor appears not to be breaking local or international law.

The founders of Swaptor "wish to remain anonymous at this time," according to Simpson. They won't need to reveal themselves to raise money: the company is headquartered in an offshore bank called the Nevis International Trust. Affiliated with the bank is a successful online gambling concern, Online Wagering Systems. Supported by advertising, Simpson claims, Swaptor has been profitable since its launch in February.

In the imagination of Net enthusiasts, offshore havens like Nevis are fervid greenhouses in which this kind of suspect operation can flower. But can it? Napster at its peak had a million and a half simultaneous users, generating a huge amount of data traffic; the company established itself in Silicon Valley, where it could gain access to the infrastructure it needed to handle this barrage of connections. Swaptor, in contrast, is headquartered in Nevis. The sole high-capacity Net pipeline to Nevis is provided by the Eastern Caribbean Fibre-Optic System, which snakes through 14 island nations between Trinidad, off the Venezuelan coast, and Tortola, near Puerto Rico. Yet this recently installed system, though it is being upgraded, has a limited capacity—not enough to push through the wash of zeroes and ones generated by a large file-swapping service. Which, one assumes, is why the "offshore" service of Swaptor is actually situated in...Virginia.

Should the recording industry decide to sue Swaptor, it wouldn't need to rely on the company or on *Technology Review* to get this information; widely available software can trace Swaptor traffic and discover that Swaptor's central index of available files is located on five servers that sit just a few miles from the Washington, DC, headquarters of the Recording Industry Association of America. (Two common monitoring programs, Traceroute and Sniffer, can be downloaded gratis from thousands of Web sites.) Not only that, Swaptor's Web site—the site from which users download the program—is hosted by a Malaysian company with an explicit policy against encouraging copyright infringement.

As Swaptor shows, the Net can be accessed from anywhere in theory, but as a practical matter, most out-of-the-way places don't have the requisite equipment. And even if people do actually locate their services in a remote land, they can be easily discovered. "I don't think most people realize how *findable* things are on the Net," says David Weekly, the software engineer and Net-music veteran who tracked down Swaptor's servers for this magazine in a few minutes. "With simple software...you can find out huge amounts of information about what people are doing in almost no time."

Once international miscreants are discovered, companies and governments already have a variety of weapons against them—and soon will have more. According to Ian Ballon of the Silicon Valley law firm Manatt, Phelps and Phillips, who serves on the American Bar Association committee on cyberspace law, even if offshore firms are legal in their home bases, their owners "have to be willing to not come back to the United States." Not only do they risk losing any assets in this country, but U.S. businesses that deal with them will also be at risk. "Any revenue the offshore business sends to them could be subject to attachment," says Ballon.

released an experimental, unfinished version on March 14, 2000. To their surprise, demand was so immediate and explosive that it forced the unprepared Pepper to shut down the Web site almost as soon as it was launched. Within hours of Gnutella's release, an embarrassed AOL pulled the plug on what it characterized as an "unauthorized freelance project."

It was too late. In an example of the seeming impossibility of stuffing the Internet cat back into the bag, thousands of people had already downloaded Gnutella. Amateur programmers promptly reverse-engineered the code and posted non-AOL versions of Gnutella on dozens of new Gnutella Web sites. Unlike Napster or Swaptor, Gnutella lets every user directly search every other user's hard drive in real time. With member computers connecting directly to each other, rather than linking through powerful central servers, these "peer-to-peer" networks have no main hub, at least in theory. As a result, there is no focal point, no single point of failure, no Gnutella world headquarters to sue or unplug. "Gnutella can withstand a band of hungry lawyers," crows the Gnutella News Web site. "It is absolutely unstoppable."

In the future, moreover, the reach of national law will increase. The Hague Conference on Private International Law is developing an international treaty explicitly intended to make outfits like Swaptor more vulnerable to legal pressure—"a bold set of rules that will profoundly change the Internet," in the phrase of James Love, director of the activist Consumer Project on Technology. (The draft treaty will be discussed at a diplomatic meeting next year.) By making it possible to apply the laws of any one country to any Internet site available in that country, the draft treaty will, Love warns, "lead to a great reduction in freedom, shrink the public domain, and diminish national sovereignty."

Rather than being a guarantee of liberty, in other words, the global nature of the Net is just as likely to lead to more governmental and corporate control.

MYTH #2: THE NET IS TOO INTERCONNECTED TO CONTROL

Before BearShare came Gnutella, a program written by Justin Frankel and Tom Pepper. Frankel and Pepper were the two lead figures in Nullsoft, a tiny software firm that America Online purchased in June 1999 for stock then worth about $80 million. Rather than resting on their laurels after the buyout, Frankel and Pepper became intrigued by the possibilities of file swapping that arose in the wake of Napster. When college network administrators tried to block Napster use on their campuses, Frankel and Pepper spent two weeks throwing together Gnutella, file-swapping software that they thought would be impossible to block. They

Peer-to-peer networks have a number of important advantages, such as the ability to search for documents in real time, as opposed to looking for them in the slowly compiled indexes of search engines such as Google and HotBot. Excited by these possibilities, such mainstream firms as Intel and Sun Microsystems have embraced peer-to-peer network technology. But the focus of interest, among both the proponents and critics of peer-to-peer networks, has been the purported impossibility of blocking them. "The only way to stop [Gnutella]," declared Thomas Hale, former CEO of the Web-music firm WiredPlanet, "is to turn off the Internet."

Such arguments have been repeated thousands of times in Internet mailing lists, Web logs and the press. But the claims for peer-to-peer's uncontrollability don't take into consideration how computers interact in the real world; a network that is absolutely decentralized is also absolutely dysfunctional. In consequence, the way today's Gnutella networks actually work is quite different from the way they have been presented in theory.

To begin, each Gnutella user isn't literally connected to every other user—that would place impossibly high demands on home computers. Instead, Gnutellites are directly connected to a few other machines on the network, each of which in turn is connected to several more machines, and so on. In this way, the whole network consists of hundreds or thousands of overlapping local clusters. When users look for a file, whether it is a copy of the Bible, a bootleg of *A.I.* or smuggled documents on the Tiananmen massacre, they pass the request to their neighbors, who search through the portion of their hard drives that they have made available for sharing. If the neighbors find what is being looked for, they send the good news back to the first machine. At the

same time, they pass on the search request to the next computer clusters in the Gnutella network, which repeat the process.

Hopping through the network, the search is repeated on thousands of machines—which leads to big problems. According to a report in December by Kelly Truelove of Clip2, a Palo Alto, CA-based consulting group that specializes in network-performance analysis, a typical Gnutella search query is 70 bytes long, equivalent to a very small computer file. But there are a great many of them—as many as 10 per second from each machine to which the user is connected. In addition, there is a constant flow of "ping" messages: the digital equivalent of "are you there?" Inundated by these short messages, the 56 kilobit-per-second modems through which most people connect to the Net are quickly overwhelmed by Gnutella. Broadband connections help surprisingly little; the speed with which the network processes requests is governed by the rate at which its slowest members can pass data through.

With BearShare, Vinnie Falco developed one potential fix. BearShare, like other new Gnutella software, automatically groups users by their ability to respond to queries, ensuring that most network traffic is routed through faster, more responsive machines. These big servers are linked into "backbone" chains that speed along most Gnutella search requests. Further unclogging the network, Clip2 has developed "reflectors"—large servers, constantly plugged into the Gnutella network, that maintain indexes of the files stored on adjacent machines. When reflectors receive search queries, they don't pass them on to their neighbors. Instead they simply answer from their own memories—"yes, computer X has this file." Finally, to speed the process of connecting to Gnutella, several groups have created "host caches," servers that maintain lists of the computers that are on the Gnutella network at a given time. When users want to log on, they simply connect with these host caches and select from the list of connected machines, thus avoiding the slow, frustrating process of trying to determine who else is online.

As their capacity improved, Gnutella-like networks soared in popularity. Napster, buffeted by legal problems, saw traffic decline 87 percent between January and May, according to the consulting firm Webnoize. Meanwhile, LimeWire, another Gnutella company, reported that the number of Gnutella users increased by a factor of 10 in the same period. "The networks are unclogging, and as a result they're growing," Truelove says. "And the content industries should be concerned about that."

But the problem with these fixes is that they reintroduce hierarchy. Gnutella, once decentralized, now has an essential backbone of important computers, Napster-like central indexes and permanent entryway servers. "We've put back almost everything that people think we've left out," says Gene Kan, a programmer who is leading a peer-to-peer project at Sun. "Ease of use always comes at some expense, and in this case the expense is that you do have a few points of failure that critically affect the ability to use the network."

Rather than being composed of an uncontrollable, shapeless mass of individual rebels, Gnutella-type networks have identifiable, centralized targets that can easily be challenged, shut down or sued. Obvious targets are the large backbone machines, which, according to peer-to-peer developers, can be identified by sending out multiple searches and requests. By tracking the answers and the number of hops they take between computers, it is possible not only to identify the Internet addresses of important sites but also to pinpoint their locations within the network.

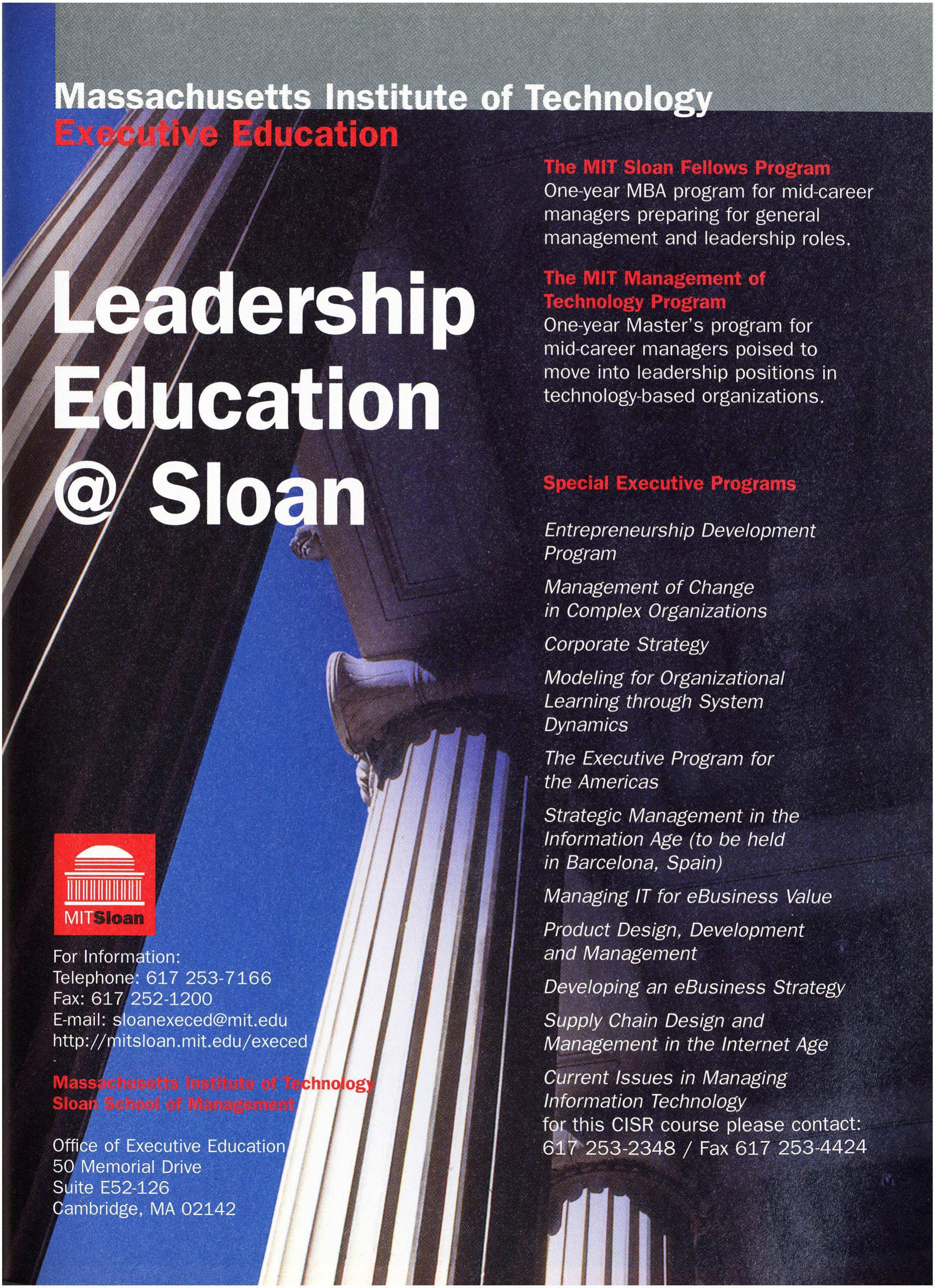
Once central machines have been identified, companies and governments have a potent legal weapon against them: their Internet service providers. "Internet service providers enjoy limitations on liability for their users' actions if they do certain things specified by law," says Jule Sigall, an Arnold and Porter lawyer who represents copyright owners. "If you tell them that their users are doing something illegal, they can limit their exposure to money damages if they do something about it when they are notified." Internet service providers, he says, do not want to threaten their customers, "but they like not being sued even more, so they've been cooperating pretty wholeheartedly" with content owners.

As Ballon of Manatt, Phelps and Phillips notes, Gnutella traffic has a distinctive digital "signature." (More technically, the packets of Gnutella data are identified in their headers.) Content companies are also learning how to "tag" digital files. The result, in Ballon's view, is easy to foresee: "At a certain point, the studios and labels and publishers will send over lists of things to block to America Online, and 40 percent of the country's Net users will no longer be able to participate in Gnutella. Do the same thing for EarthLink and MSN, and you're drastically shrinking the pool of available users." Indeed, the governments of China and Saudi Arabia have successfully pursued a similar strategy for political ends.

Perhaps sensing that Gnutella cannot escape the eye of authority, bleeding-edge hackers have searched for still better solutions. Determined to create a free-speech haven, a Scottish activist/programmer named Ian Clarke in 1999 began work on a Gnutella-like network called Freenet that would be even more difficult to control, because it would encrypt all files and distribute them in chunks that constantly shifted location. Unsurprisingly, it has attracted enormous media attention. But the system is so incomplete—searchability is an issue—that one cannot judge whether it will ever be widely used. (A small number of people are already using Freenet. Most of them are pornography fans, but a few, according to Clarke, are Chinese dissidents who employ Freenet to escape official scrutiny.) Even if Freenet does not end up in the crowded graveyard of vaporware, Internet service providers can always pull the plug—treating Freenet, in essence, as an unsupported feature, in the way that many providers today do not support telnet, Usenet and other less popular services.

MYTH #3: THE NET IS TOO FILLED WITH HACKERS TO CONTROL

It was a classic act of hubris. The Secure Digital Music Initiative, a consortium of nearly 200 technology firms and record labels, thought the software it had developed to block illegal copying of music was so good that last September it issued an "open letter to the digital community" daring hackers to try their best to break it. The result was a fiasco. Within three weeks, at least four teams broke the code, and hacks were soon distributed widely across the Internet. In the folklore of the Net, the initiative's challenge became one more example of a general truth: any method of controlling digital information will fail, because someone will always find a way around it—and spread the hack around the Internet.



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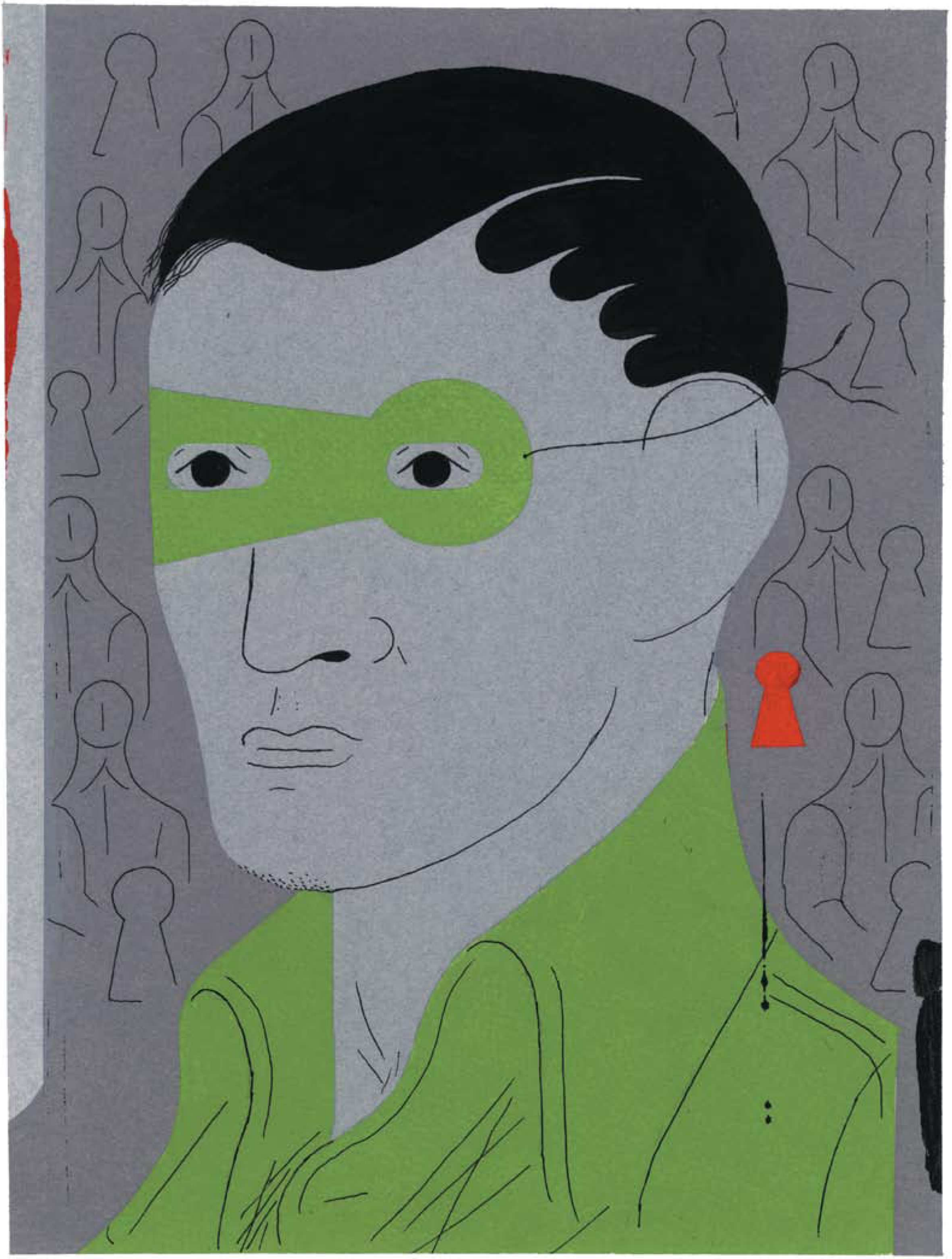

"There are no technical fixes," says Bruce Schneier, cofounder of Counterpane Internet Security. "People have tried to lock up digital information for as long as computer networks have existed, and they have never succeeded. Sooner or later, somebody has always figured out how to pick the locks."

But software is not the only means of controlling digital information: it's also possible to build such controls into hardware itself, and there are technical means available today to make hardware controls so difficult to crack that it will not be practical to even try. "I can write a program that lets you break the copy protection on a music file," says Dan Farmer, an independent computer security consultant in San Francisco. "But I can't write a program that solders new connections onto a chip for you."

In other words, those who claim that the Net cannot be controlled because the world's hackers will inevitably break any protection scheme are not taking into account that the Internet runs on hardware—and that this hardware is, in large part, the product of marketing decisions, not technological givens. Take, for example, Content Protection for Recordable Media, a proposal issued late last year by IBM, Intel, Toshiba and Matsushita Electric *(see "The End of Free Music?" TR April 2001)*. The four companies developed a way to extend an identification system already used in DVDs and DVD players to memory chips, portable storage devices and, conceivably, computer hard drives. Under this identification scheme, people who downloaded music, videos, or other copyrighted material would be able to play it only on devices with the proper identification codes.

In addition to restricting unauthorized copies, it was widely reported that the technology also had the potential to interfere with other, less controversial practices, such as backing up files from one hard drive onto another. In part because of controversy surrounding the technology, the companies withdrew the plan from consideration as an industrywide standard in February. But the point is clear: the technology has been tabled because its promoters believed it wasn't profitable, not because it would not work. This and other hardware schemes have the potential to radically limit what people can do with networking technology.

Some hardware protection methods already exist. Stephen King released his e-book *Riding the Bullet* in March 2000, in what were effectively two different versions: a file that could be read only on specialized electronic devices—electronic books—and a file that could be read on computer monitors. Even though the text was available for free at Amazon.com, some people went to the trouble of breaking the encryption on the computer file anyway; distributed from Switzerland, it was available on the Internet within three days. But the electronic-book version was never cracked, because e-books, unlike computers, cannot do two things at once. "On a computer, you can always run one program to circumvent another," says Martin Eberhard, former head of NuvoMedia, the developer of the Rocket eBook. "If a book is on a computer screen, it exists in video memory somewhere, and someone will always be able to figure out how to get at it."

Eberhard's e-books, by contrast, were deliberately designed to make multitasking impossible. True, future e-books could, like computers, perform two tasks simultaneously, but publishers could refuse to license electronic books to their manufacturers, in much the same way that film studios refuse to allow their content to be used on DVD machines that don't follow certain rules. And even computers themselves, in Eberhard's view, could be "rearchitected," with added hardware that performs specific, controlling tasks. "If people have to rip up their motherboards to send around free music," he says, "there will be a lot less free music on the Net.…It would be an ugly solution, but it would work."

Of course, consumers will avoid products that are inconvenient. A leading example is digital audio tape recorders, which by law are burdened with so many copy protection features that consumers generally have rejected them. But to assume that companies involved with digital media cannot come up with an acceptable and effective means of control is to commit, in reverse, the same act of hubris that the Secure Music Digital Initiative did, when it assumed that clever people couldn't break its software. And if the hardware industry resists making copy-protected devices, says Justin Hughes, an Internet-law specialist at the University of California, Los Angeles, an appeal to Congress may be "just a matter of time." If the Internet proves difficult to control, he says, "you will see legislation mandating that hardware adhere to certain standard rules, just like we insist that cars have certain antipollution methods."

"To say that a particular technology guarantees a kind of anarchic utopia is just technological determinism," he says. "This argument should be ignored, because the real question is not whether the Net will be tamed, but why and how we tame it."

We are in the beginning stages of the transfer of most of society's functions—working, socializing, shopping, acting politically—from what Internet denizens jokingly call "meatspace" into the virtual domain. In the real world, these functions are wrapped in a thicket of regulations and cultural norms that are, for the most part, accepted. Some free-speech absolutists dislike libel laws, but it is generally believed that the chilling effect on discourse they exert is balanced by their ability to punish gratuitous false attacks on private individuals. Regulations on the Net need not be any more obnoxious. "If the whole neighborhood's online, it's okay to have a cop on the beat," says Schneier.

The risk, of course, is overreaching—of using law and technology to make the Internet a locus of near absolute control, rather than near absolute freedom. Paradoxically, the myth of unfettered online liberty may help bring this undesirable prospect closer to reality. "Governments are going to set down rules," says Hughes, "and if you spend all your time fighting the existence of rules you won't have much chance to make sure the rules are good ones."

In other words, hackers may be their own worst enemies. By claiming that the Net is inherently uncontrollable, they are absenting themselves from the inevitable process of creating the system that will control it. Having given up any attempt to set the rules, they are unavoidably allowing the rules to be set for them, largely by business. Corporations are by no means intrinsically malign, but it is folly to think that their interests will always dovetail with those of the public. The best way to counterbalance Big Money's inevitable, even understandable, efforts to shape the Net into an environment of its liking is through the untidy, squabbling process of democratic governance—the exact process rejected by those who place their faith in the endless ability of anonymous hackers to circumvent any controls. An important step toward creating the kind of online future we want is to abandon the persistent myth that *information wants to be free.* TR

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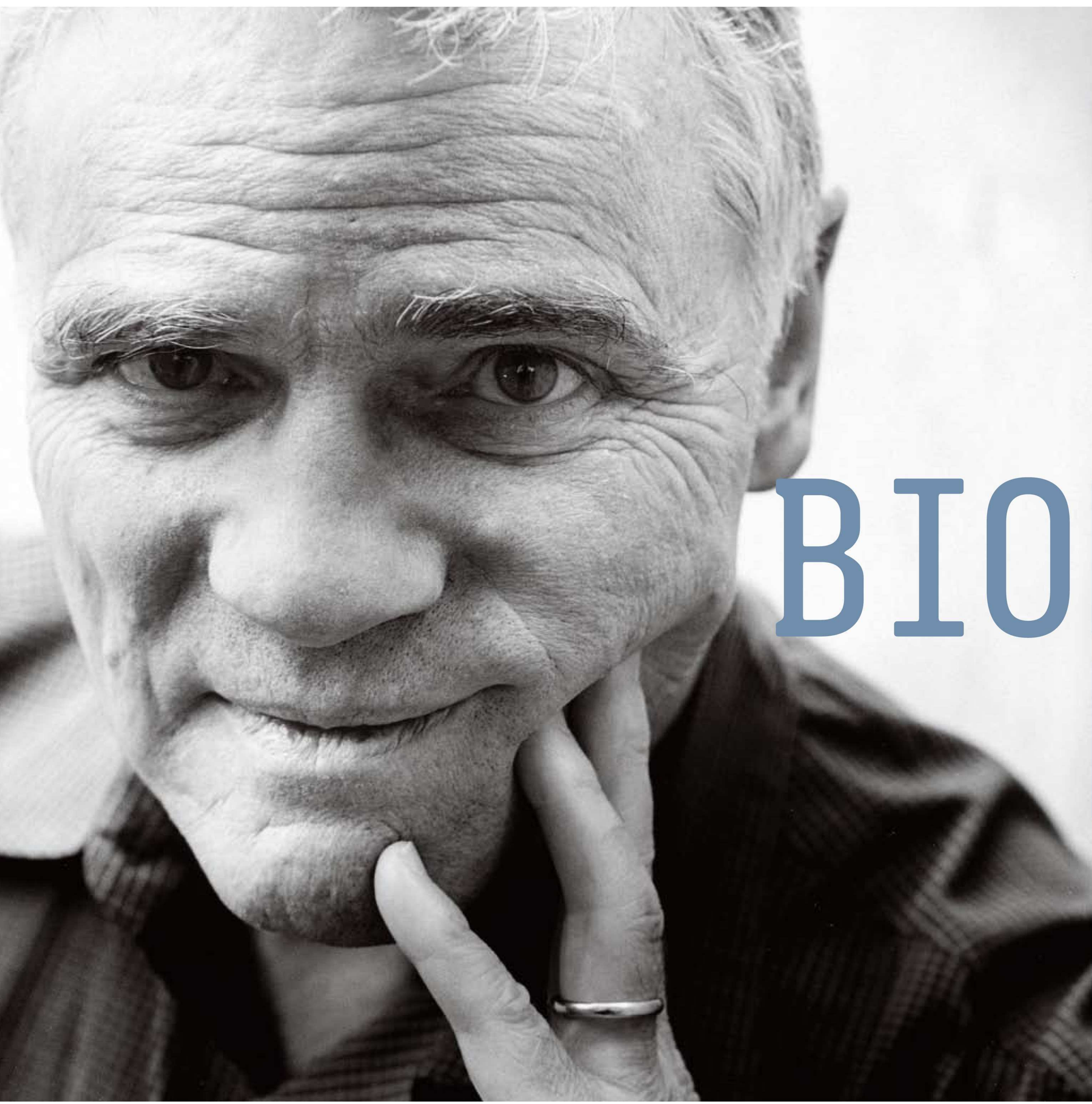


Q & A

UNDER BIOLOGY'S HOOD

From the man who gave us the automated DNA sequencer comes a whole new approach to the study of life. Through "systems biology," says Leroy Hood, medicine will be utterly transformed.

Photographs by Anne Hamersky

THE MULTIBILLION-DOLLAR HUMAN GENOME PROJECT'S EFFORT to detail the entire set of human genes was biology's moonshot. But it might have never made it off the launch pad without one key piece of technology—the automated DNA sequencer. Labs crammed full of these machines, each rapidly determining the sequence of bits of DNA, were the fuel that made the project feasible. Leading the team that developed the sequencer shortly before the genome project was initiated in the mid-1980s is just one of the achievements that has helped turn Montana native Leroy Hood into a biotech superstar. Now 62, the Caltech-trained biologist has laid the foundations for a string of biotech companies, helped unravel the mysteries of the immune system and mad-cow-disease-causing prions, built—with $12 million from Bill Gates—a molecular biotechnology department at the University of Washington, and left the university behind to found his own institute, Seattle's Institute for Systems Biology.

Founded in January 2000 with an anonymous $5 million donation, the Institute is a vehicle for what Hood sees as a whole new kind of biology—one that focuses, not on individual genes, proteins and other factors, but on how they come together in complicated systems to make us healthy or ill. Fulfilling this vision of "systems biology" will require that researchers mix lab work with computer modeling and eschew highly focused and hypothesis-driven experiments in favor of the factory style approach typified by the genome project itself. The payoff, Hood says, will be a fundamental transformation of medicine. And he's eager to develop the technologies to make it happen.

Doing that, while at the same time trying to build his institute's endowment, keeps the biologist busy. *TR* senior editor Rebecca Zacks caught up with Hood this spring in a series of phone calls—5:30 in the morning was convenient for him—to his home, office, and an airport lounge.

TR: You're perhaps best known for leading the team that invented the DNA sequencer as a young Caltech professor in the early 1980s. But that was just one of four technologies you worked on at Caltech, right?
HOOD: We had a deep interest in developing tools that would push biology ahead over the next 15 years. We had a clear vision of four instruments that would change the world: the DNA synthesizer, the DNA sequencer, the protein synthesizer, and the protein sequencer. They allowed one to decipher and synthesize biological information more effectively than was previously possible.

TR: Why are these tools so important?
HOOD: The relationship between biology and technology is interesting. Most biologists are indifferent to technology—they use it, but they don't really see it as a fundamental part of biology. Indeed, it is new or more sensitive technology that can open up new horizons in biology. A great example is the protein sequencer [a device that determines the identity and order of the amino-acid building blocks that make up a particular protein]. The sequencer we developed was about 100 times more sensitive than previous versions. It let us analyze many proteins that were heretofore utterly inaccessible to analysis. We carried out six projects and each of them opened up a new and interesting field. For example, we sequenced a hormone called erythropoietin with Amgen, and that sequence was key to their cloning the gene which led directly to the development of the first billion-dollar drug of the biotech industry.

TR: Still, you didn't always get an enthusiastic response when you proposed these tools—even with the DNA sequencer?
HOOD: I sent in a couple of grants to the National Institutes of Health in the early '80s when we were just starting to develop the DNA sequencer, and neither was funded. Comments were, "Grad students can do it cheaper," or "It's impossible."

I went to the president of Caltech in '78 or '79 and said, "Look, we are developing four instruments that will change biology. My colleagues are suggesting that they should be made available to the general scientific community. Hence, we should commercialize them." And he said, "Caltech isn't really interested in commercialization. If you want to, you have permission to go out and commercialize them, but we're not interested in that kind of thing." Over the next two years I went to about 19 companies and got 19 *no*s. It was around 1980 when a venture capitalist from San Francisco called me and said, "I'll put in a couple of million to develop these instruments you've been shopping around. Why don't we start a company?" That company became Applied Biosystems [which merged with scientific instrument maker Perkin-Elmer in a $330 million stock deal in 1993].

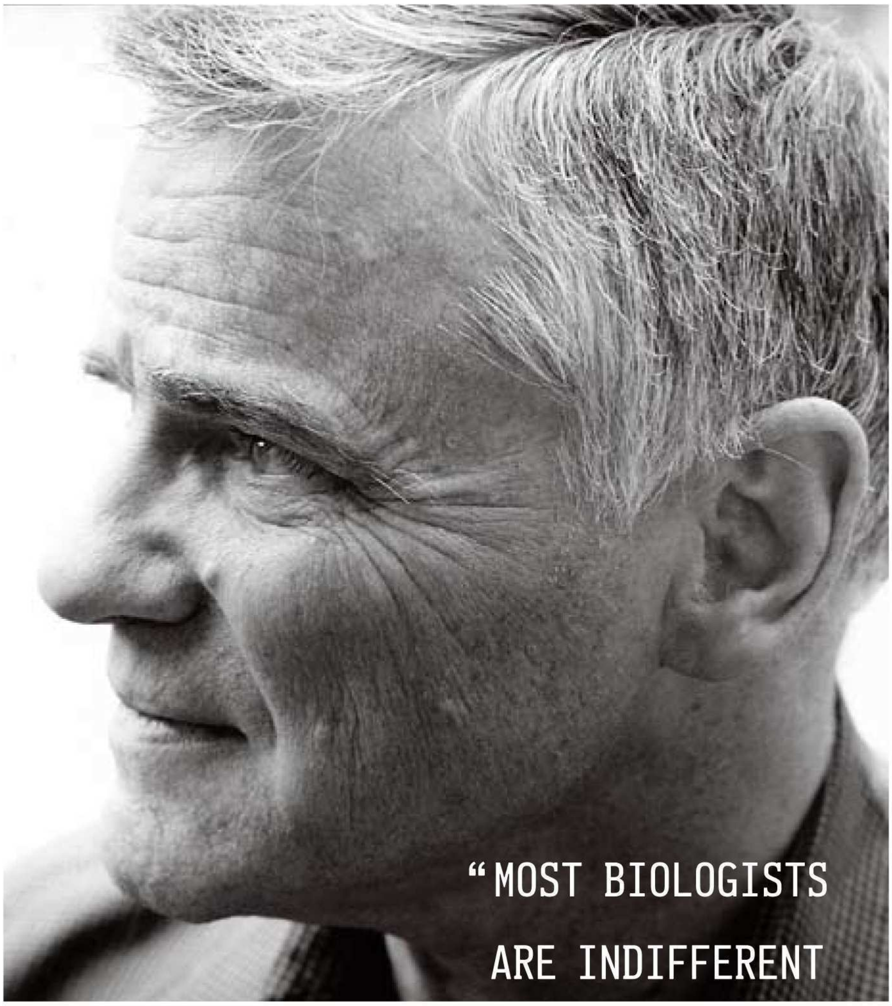
TR: What other firms did you help found?
HOOD: I was in on the beginning of Amgen, and I've been involved in founding seven or eight other companies since. I got involved in the biotech revolution in the early days. It was intellectually exciting to be involved as a scientific advisor. One learned an enormous new science and enjoyed the science without any of the responsibility of making money. Companies go through this maturational process where they need founding scientists as scientific advisors for the first few years, and then they mature and function independently. It is a healthy process.

TR: Were you ever tempted to get more involved in the business side?
HOOD: Not at all. The key issue always for me was the freedom to approach new problems. With a company, no matter how flexible the opening opportunity seems, in the end you have to make money and subjugate your interests to making money. What is so wonderful about academic research is you can explore what you wish. The other issue is the ability to attack long-term problems. You are not constrained to making money within two or at most three years.

TR: You thought the Human Genome Project was worth long-term investment, but initially not everybody felt that way?
HOOD: I went to the first meeting held on the Human Genome Project in the spring of '85 at the University of California, Santa Cruz. Robert Sinsheimer, the chancellor, had $35 million and was considering spending it on an institute to sequence the human genome. He invited 10 or 12 scientists to consider this for two or three days. My lab had started working on the DNA sequencer in the early '80s, and the publication describing the first prototype was in 1986. So the Human Genome Project and DNA sequencing came together.

There were three things that stood out in my mind about that first meeting. One was the enormous technological challenges the Human Genome Project presented, both in sequencing and mapping, but also in computation and analysis. The second thing that was exciting was to see how it would transform biology and medicine. I was an advocate for this project, and was there ever bitter opposition. Hostile, aggressive and negative interactions resulted. And the reason for that, which is the third thing that really impressed me, is the genome introduced to biology a completely new approach, which I've since come to call "discovery science." It's the idea that you take an object and you define all its elements and you create a database of information quite independent of the more conventional hypothesis-driven view.

What people really resisted in the Human Genome Project were two major things. One, "It's going to cost too much money—it's going to take money away from me." And this was never correct. The project started with a large bolus of new money and has since brought lots of new money to science. The second argument against the Human Genome Project was that it was trivial, it wasn't really science. It was referred to as a fishing expedition, or a mindless collecting of facts. What they did not realize is how these databases were



going to transform how we think about biology and medicine.

TR: Can you describe those changes?
HOOD: First, discovery science is now an accepted concept. Second, the human genome has provided us with a genetics parts list for humans and the other model organisms whose genomes have been sequenced. We must do biology to figure out how these parts function, and now we have them—genes, control sequences, etc.—in databases. Third, the Human Genome Project has given us access to human variability, the genetic variations which make humans different from one another—different in physiology and different in disease predisposition. And it's in this arena that medicine will be utterly transformed over the next 20 years or so.

TR: Do these changes raise ethical issues?
HOOD: I think a big issue is how we're going to educate the public about the revolution that is coming in medicine. What will happen over that 20- to 25-year time period is that we will move from what I call reactive medicine—you get sick, they try to fix you—to what I would call predictive medicine—they look, for example, at your genes and determine whether you have a bad gene for breast cancer, so you will have a 70 percent likelihood that at the age of 60 you'll have breast cancer. In this stage, you can make predictions, but you can't do much about it. The final stage will be the preventive stage where we will be able to take defective genes, understand the pathways in which they operate and how to manipulate those pathways so you can circumvent the limitations of the defective gene. Ideally, you would be able to take pills that could reverse those limitations in a preventive fashion.

This preventive medicine is going to wreak enormous challenges for how we educate physicians. The fact is, the physicians we're educating today are going to be practicing in that era, and most of them do not have the faintest idea about the coming revolution in medicine. Medical schools are, in general, resistant to responding to this certain future. In my experiences, their attitude is, "Well, that is an interesting proposition, but we do not have time to think about it today." The same will be true of society at large. There are also the ethical issues of genetic privacy, germ-line genetic engineering, and genes that influence human behavior.

TR: Why is the lay public's knowledge of medicine and science important?
HOOD: In the end it is the public that places two limitations on how we do science. One is funding and the second is the regulations that govern how we do science. Accordingly, it is imperative that we somehow reach out to the lay public and educate them about these issues.

TR: In a nutshell, what is systems biology?
HOOD: Suppose you wanted to figure out how a car works. The way biology has done it in the past is to create a group of specialists that would study individual parts—the wheels, the brakes and the ignition. Each group of specialists would talk within their own group but not to the members of the other groups. What systems biology does is attempt to use discovery science to define all the elements in the system, all the components of the car. Then it perturbs the car—accelerate, brake, etc.—and attempts to define the relationships of the elements one to another at various levels—mechanical, electrical, etc. Finally, systems approaches integrate these different kinds of measurements and data in a way that one can begin to formulate graphical displays and finally mathematical models that ultimately will give one insight into the structure and functioning of the car.

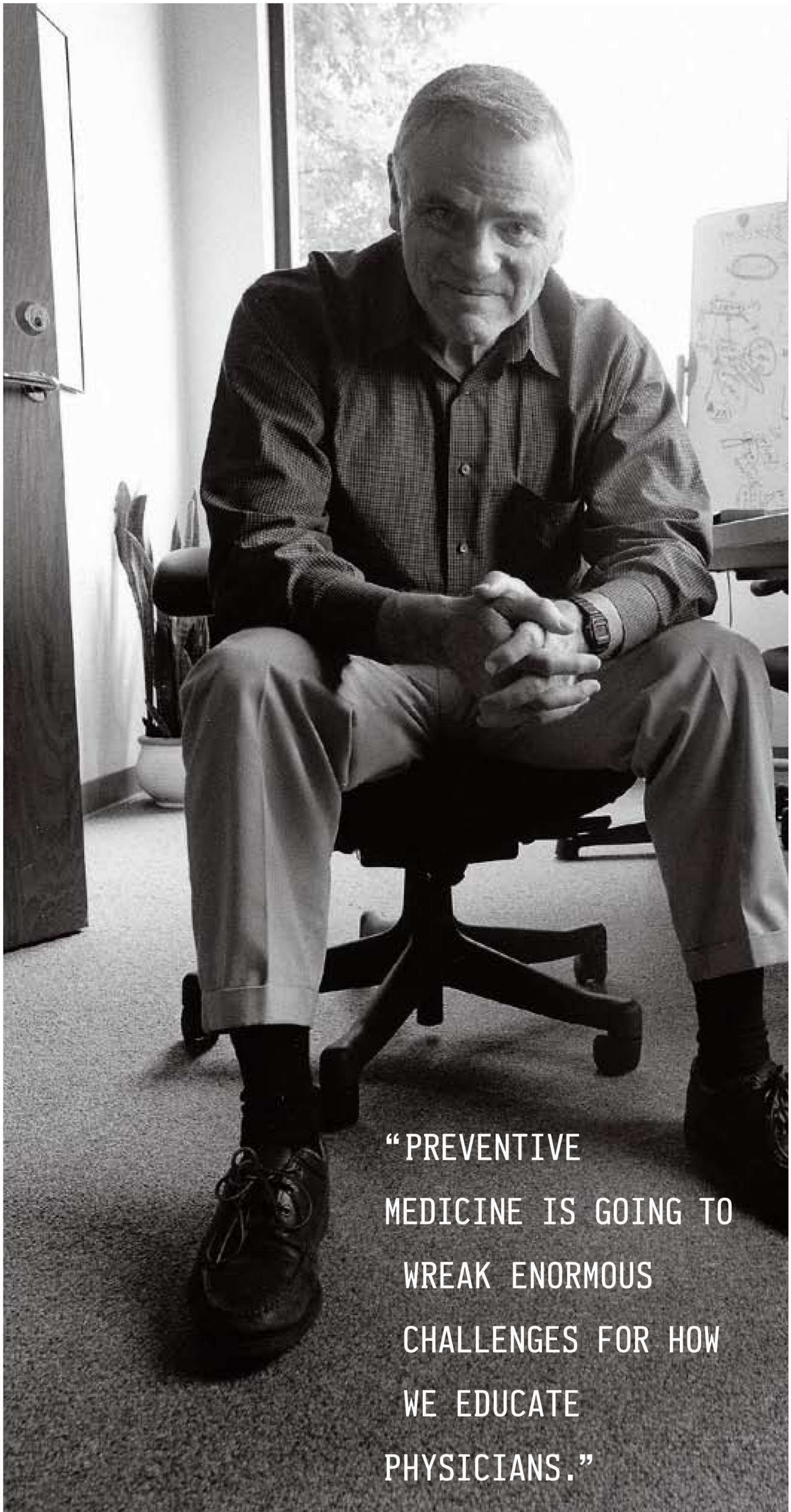
That is basically what systems biology is about. It is taking a biological system, identifying its elements, perturbing it in a model system, capturing information at the DNA, RNA, protein, protein interaction, informational pathway and informational network levels, and integrating and graphically displaying [that information], and then developing mathematical models that will describe the structure and behavior of the system.

"MOST BIOLOGISTS ARE INDIFFERENT TO TECHNOLOGY—THEY DON'T SEE IT AS FUNDAMENTAL."

TR: What does that allow you to do?
HOOD: It allows you to understand the system and how it functions. If you are a pharmaceutical company, it suggests that there are critical points in these informational networks at which one can begin to attack the system, manipulate it, circumvent the limitations of defective genes. We are at the earliest stages of learning how to do mathematical formulations. Once we do, I think it will transform how one identifies drug targets, how one deals with potential side effects of drugs, and how one determines whether a particular drug that has already been approved might do something else that is even more interesting.

TR: Is all this modeling moving biology out of the wet lab and into the computer—what some call "biology in silico?"
HOOD: Not at all. The message is that we have to integrate the computational tools with the data generated from biological tools. The systems-model process is really iterative with data generation, modeling, data quantitation, etc. The first time you go around the loop, you find that your model is not very good, so you have to do more experiments to improve it. This process repeats itself until you get to a place where the predictions you can make with the model are in conjunction with the experimental data you generate. You will never make progress in biology if you believe you can attack biological complexity solely in silico. The heart of biology is complexity, and we are going to unravel complexity only by doing biological experiments. But the integration with modeling and the graphic display of complexity is a central feature of what we're trying to do at the Institute for Systems Biology.

TR: Why did you start the institute?
HOOD: I moved from Caltech to the University of Washington School of Medicine in 1992 to start the Department of Molecular Biotechnology. The vision of the department was to be cross disciplinary; that we were to hire engineers, applied physicists and computer scientists, as well as biologists. By 1995 or so, we had filled all the space we had been allocated. The department was enormously successful. We had terrific people. We had great funding. So I went to the president of the University of Washington and asked to build a new structure to expand the department in keeping



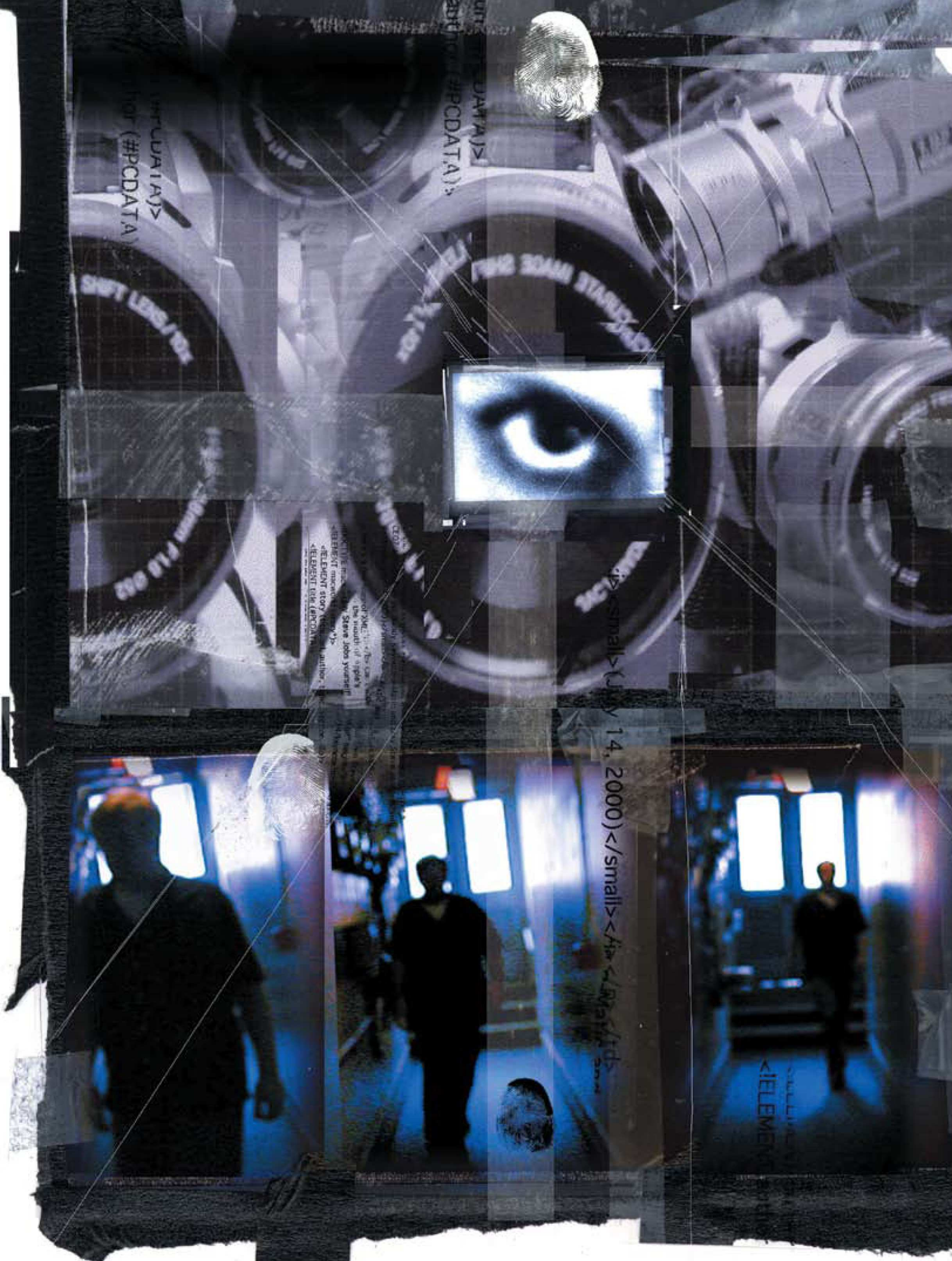
with the already apparent opportunities of systems biology. The president said no, that there were eight or nine other projects in line and that I would have to wait 10 or more years before I could get a building. I then decided to start the institute. I spent about four years trying to create it within the School of Medicine at the University of Washington, but in the end, I had to resign and establish an independent nonprofit institute. When all was said and done, I realized that the university culture and bureaucracy just could not have sufficient flexibility for the needs of an institute attempting to respond to the opportunities emerging from the Human Genome Project. The Institute for Systems Biology has been operating for a little more than a year. We have seven cross-disciplinary faculty and have grown from a staff of two to a staff of 160. We've established six technology platforms, we've been successful in getting grants and industrial support, we've established a number of industrial partnerships, and we've published a series of exciting papers, including one that is a proof of principle for the Institute.

TR: What technologies are you developing?
HOOD: We are working on ink-jet synthesizers that can be used to build oligonucleotide gene chips [stamp-sized wafers capable of analyzing thousands of genes at a time] in a more flexible manner than can be done with the alternative technology—photolithography. We are setting up a very large-scale proteomics production line [to identify and characterize proteins and their functions]. This is a very important technology for the post-genomic era. We're working on sophisticated cell sorters that will be able to take complex populations of cells and very rapidly separate different cell types. We are working on new ways of determining protein-protein and protein-DNA interactions. These technologies are high throughput and global in nature—they look at all or most genes or proteins. At the same time, we are attempting to develop software that is good for the visualization of biological complexity, software that can automate the process of building and optimizing the models. Obviously, we have to develop computational tools that will capture information from each of these different technologies.

TR: What sorts of biological problems is the institute tackling?
HOOD: One area that is important to the institute is human genetic variation and its correlation with physiology or disease predisposition. We are developing technologies for identifying and typing human variation more effectively in large populations. We are also very interested in immunity, stem cell research, and cancer. In addition, we are using yeast as a model system to work out our high-throughput technologies and our strategies for doing systems biology.

TR: Any plans to commercialize this work?
HOOD: We are more than ready to spin out intellectual property to industry. We can either license the intellectual property to preexisting companies, or we can spin it out as new companies. Over the past year, we have already spun out two companies: MacroGenics, which uses the tools of genomics and proteomics to discover targets on cancer cells that can be used for immune-system-based therapies; and Cytopeia, which is developing technologies to further multiparameter, high-speed cell sorting and enlarge its applications. The forte of the Institute is not doing short-term research, but rather taking on long-term, challenging problems.

TR: Those long-term problems are the sort you've said are best tackled in an academic setting—yet in the past few years you felt you weren't able to do so at the University of Washington. Do you think the obstacles you encountered there are endemic to universities these days?
HOOD: I do. The question is a very interesting one: are universities going to be able to compete in this new world of post-genome biology? The issue is open. As I noted earlier, the issues center around leadership, flexibility, timeliness, resources—and very new ways of doing science. It has been a struggle for me for the last five years. But possibly these changes will come more easily now that we understand the issues and the opportunities that are emerging from systems biology. What is clear is that this approach will transform biology and medicine. TR



BIG BROTHER LOGS ON

IS PRIVACY A RIGHT OR A PRIVILEGE? RECENT DEVELOPMENTS IN SURVEILLANCE TECHNOLOGY ARE CALLING THE CONCEPT OF PRIVACY INTO QUESTION, AS CAMERAS INVADE OUR STREETS AND SOFTWARE RECORDS OUR FACIAL EXPRESSIONS WHILE WE SHOP. IS OUR LOSS OF PRIVACY INEVITABLE? BY IVAN AMATO/ILLUSTRATIONS BY ANASTASIA VASILAKIS

THE DOOR TO PARANOIA OPENS BENIGNLY—AND EARLY. JUST THINK OF SANTA. HE KNOWS WHEN YOU ARE SLEEPING. HE KNOWS WHEN YOU'RE AWAKE. HE KNOWS IF YOU'VE BEEN BAD or good, for goodness' sake. And he knows these things all the time, even though you can't see him. Millions of kids all over the world happily and wholeheartedly believe in ubiquitous surveillance as a de facto piece of the annual Christmas present-getting machine. Parents just shake their heads in adoring wonder.

But those same parents might be shocked to learn how short the journey is from the pleasant surveillance fantasy of Santa to the freedom-squashing invasion of Big Brother. In the world detailed by George Orwell in the novel *1984,* surveillance cameras follow every move a person makes, and the slightest misstep, or apparent misstep, summons the authorities. Now, similarly, police departments, government agencies, banks, merchants, amusement parks, sports arenas, nanny-watching homeowners, swimming-pool operators, and employers are deploying cameras, pattern recognition algorithms, databases of information, and biometric tools that when taken as a whole can be combined into automated surveillance networks able to track just about anyone, just about anywhere.

THE DRAMA OF PERVASIVE SURVEILLANCE IS BEING PLAYED OUT IN ORWELL'S NATIVE LAND, THE UNITED KINGDOM, WHICH OPERATES MORE CLOSED-CIRCUIT CAMERAS PER CAPITA THAN ANY OTHER COUNTRY IN THE WORLD.

While none of us is under 24-hour surveillance yet, the writing is on the wall. As Scott McNealy, CEO of Sun Microsystems, starkly told reporters in 1999, "You already have zero privacy. Get over it." The techno-entrepreneurs who are developing and marketing these tools anticipate good things to come, such as reduced crime rates in urban environments, computer interfaces that will read eye movements and navigate the Web for you, and fingerprint or facial recognition systems and other biometric technologies that guarantee your identity and eliminate the need for passwords, PIN numbers and access cards—even identifying potential terrorists before they can strike.

But privacy advocates paint a far dimmer picture of this same future, accepting its reality while questioning whether it can be managed responsibly. "The technology is developing at the speed of light, but the privacy laws to protect us are back in the Stone Age," says Barry Steinhardt, associate director of the American Civil Liberties Union, which is among several groups that have tried, so far almost universally unsuccessfully, to introduce legislation aimed at protecting privacy. "We may not end up with an Orwellian society run by malevolent dictators, but it will be a surveillance society where none of the detail of our daily lives will escape notice and where much of that detail will be recorded."

THE FIFTH UTILITY

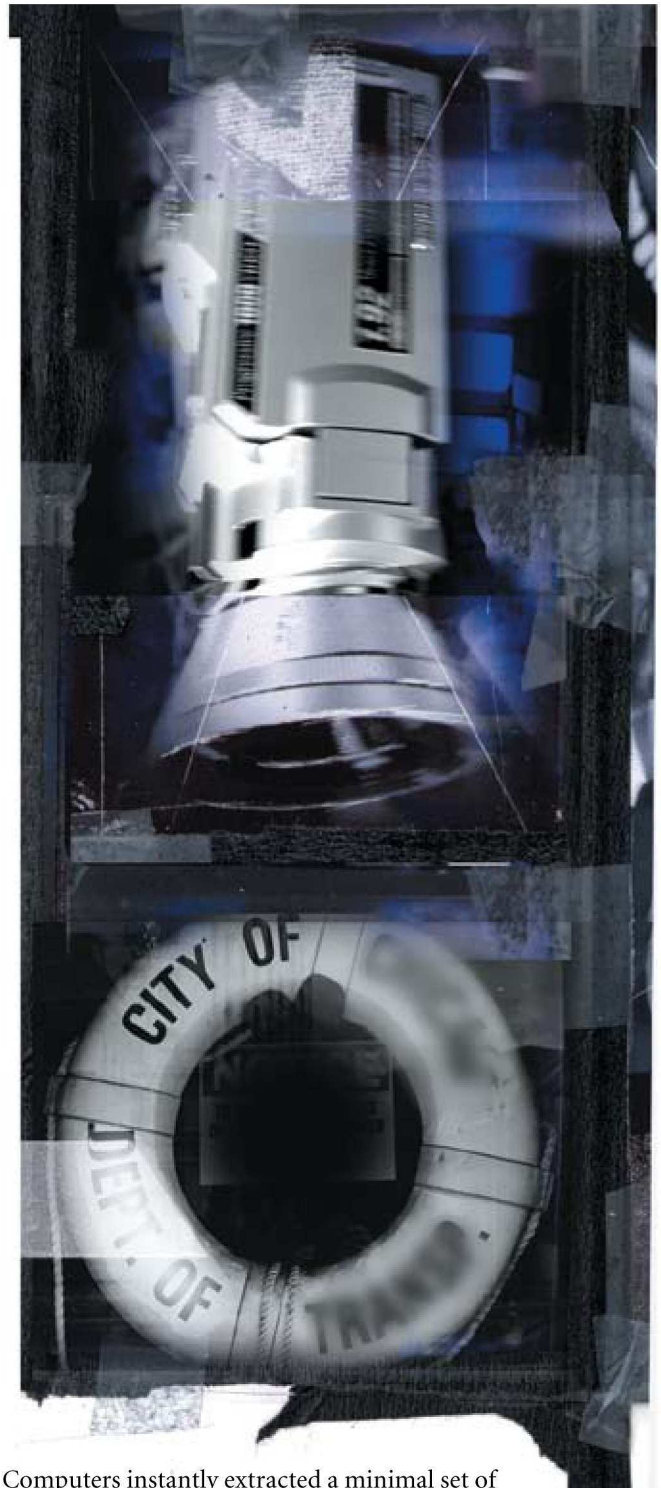
In many ways, the drama of pervasive surveillance is being played out first in Orwell's native land, the United Kingdom, which operates more closed-circuit cameras per capita than any other country in the world. This very public surveillance began in 1986 on an industrial estate near the town of King's Lynn, approximately 100 kilometers north of London. Prior to the installation of three video cameras, a total of 58 crimes had been reported on the estate. None was reported over the next two years. In 1995, buoyed by that success, the government made matching grants available to other cities and towns that wanted to install public surveillance cameras—and things took off from there.

Most of these closed-circuit TV systems are installed in business districts or shopping centers by British Telecommunications, the national phone network, and jointly operated and managed by law enforcement and private industry. In addition, some townships are using BT to hook up video telephony, a technology that allows transmission of video images via telephone lines—but in a monitor-friendly network that provides officials quick and easy remote access to the images. On another front, the U.K. Home Office, the government department responsible for internal affairs in England and Wales, is starting construction of what promises to be the world's biggest road and vehicle surveillance network, a comprehensive system of cameras, vehicle and driver databases, and microwave and phone-based communications links that will be able to identify and track the movements of vehicles nearly nationwide. All told, the country's electronic eyes are becoming so prevalent that Stephen Graham of the Centre for Urban Technology at the University of Newcastle upon Tyne has dubbed them a "fifth utility," joining water, gas, electric and telephones.

The United States and many other parts of the developed world are not far behind in video surveillance. Just look at the cameras looking at you. They're in ATMs, banks, stores, casinos, lobbies, hallways, desktops, and along highways, main streets and even side streets. And those are the cameras you can see. Companies like All Security Systems of Miami, FL, advertise Clock Cameras, Exit Sign Cameras, Smoke Detector Cameras, and Covert Tie and Button Cams, as well as Nanny Cams and other easily hidden eyes, some of which send video signals wirelessly to a recorder located elsewhere.

But cameras seem relatively benign when compared to new technology being developed and deployed. Until recently, closed-circuit systems have fed video signals to monitors, which human beings had to watch in real time, or sent the images to recording media for storage. Now, however, the job of spotting suspicious people and behavior in this stream of electronic imagery is becoming automatic, with computers programmed with special algorithms for matching video pixel patterns to stored patterns associated with criminals or criminal actions—and the machines themselves passing initial judgment on whether a behavior is normal.

For example, last January at the Super Bowl in Tampa, FL, law enforcement agencies, without announcement, deployed a face recognition system from Viisage Technology of Littleton, MA. Cameras snapped face shots of fans entering the stadium.



Computers instantly extracted a minimal set of features from each captured face, a so-called eigenface, and then compared the eigenfaces to those of criminals, stored in a database. The system purportedly found 19 possible matches, although no one was arrested as a result of the test. Less than six months later, in mid-July, Tampa police sparked public protests after deploying a face recognition system from Visionics, of Jersey City, NJ, to scan city sidewalks for suspected criminals and runaways.

And this is just the beginning of the technology being piloted and prototyped to watch you—and judge your behavior. Beginning in 1997, the U.S. Defense Advanced Research Projects Agency (DARPA) funded some 20 projects under a three-year program called Video Surveillance and Monitoring. That effort has just gathered new momentum under a $50 million follow-up program known as Human ID at a Distance. The aim is to determine if it's feasible to identify specific individuals at distances up to 150 meters.

Under the program, researchers at Carnegie Mellon University in Pittsburgh are investigating whether a remote sensing technique known as "hyperspectral imaging"—a technology typically used by satellites to find minerals or peer through military camouflage—can be adapted for identifying specific human beings by measuring the color spectrum emitted by their skin. Skin absorbs, reflects and emits distinct patterns of color, and those patterns are specific enough to individual people to serve as spectral signatures. Such systems already work. But according to Robert Collins, a computer scientist at Carnegie Mellon's Robotics Institute, the process currently requires a person to sit stiffly in a chair as a sensor sweeps through hundreds of emitted wavelengths over a period of about five seconds. "Ideally, what will happen is we'll find some small group of wavelengths that we can use to distinguish people," explains Collins. That could reduce the scan time to a fraction of a second.

Another approach being developed involves a video-based network of sensors that would automatically measure such characteristics as leg length and waist width to provide, as Collins says, "the measurements you give to a tailor." The idea here, he says, is that those numbers should be able to serve as a kind of body fingerprint for identifying specific individuals.

There is no shortage of cleverness when it comes to building the surveillance state. At the Georgia Institute of Technology, scientists are developing sensor-riddled "smart floors" that can identify people by the "force profiles" of their walking feet. Meanwhile, Princeton, NJ-based Sarnoff is working toward an antiterrorist technique that uses a special camera to identify individuals from a hundred meters off by the patterns of color, striation and speckles in their irises. This isn't easy, since the iris and its elements move so quickly relative to a distant camera that the technical task bears some resemblance to "tracking a ballistic missile," says Norman Winarsky, president of nVention, Sarnoff's venture technology company. Still, the technology is coming.

Beyond identity is intention—and there are technologies in the works for divining that as well. IBM has introduced a software product called BlueEyes *(see "Behind BlueEyes,"* TR *May 2001)* that's currently in use at retail stores to record customers' facial expressions and eye movements, tracking the effectiveness of in-store promotions. And psychologist Jeffrey Cohn of Carnegie Mellon's Robotics Institute and colleagues have been trying to teach machines an even more precise way to detect facial expressions.

From video signals, the Carnegie Mellon system detects and tracks both invariant aspects of a face, such as the distance between the eyes, and transient ones, like skin furrows and smile wrinkles. This raw data is then reclassified as representing elemental actions of the face. Finally, a neural network correlates combinations of these measurable units to actual expressions. While this falls short of robotic detection of human intentions, many facial expressions reflect human emotions, such as fear, happiness or rage, which, in turn, often serve as visible signs of intentions.

Cohn points out that this particular work is just part of the team's more encompassing "goal of developing computer systems that can detect human activity, recognize the people involved, understand their behavior, and respond appropriately." In short, the effort could help lead to the kind of ubiquitous surveillance

system that can automatically scan collective human activity for signs of anything from heart-attack-inducing Type-A behavior to sexual harassment to daydreaming at the wheel to homicidal rage.

THE GOOD, THE BAD AND THE WELL-INTENTIONED

The list of emerging technological wonders goes on and on, which is why many observers argue it's no longer a question of whether ubiquitous surveillance will be applied, but under what guidelines it will operate—and to what end.

"Like most powerful technologies, total surveillance will almost certainly bring both good and bad things into life," says James Wayman, a former National Security Agency contractor who now directs human identification research at San Jose State University in California. Specifically, he notes, it will combine laudable benefits in convenience and public safety with a potentially lamentable erosion of privacy.

These contradictory values often trigger vigorous debate over whether it will all be worth it. The glass-half-full crowd contends that the very infrastructure of surveillance that conjures fears of Big Brother will actually make life easier and safer for most people. Consider the benefits of the "computer-aided drowning detection and prevention" system that Boulogne, France-based Poseidon Technologies has installed in nine swimming pools in France, England, the Netherlands and Canada. In these systems, a collection of overhead and in-pool cameras relentlessly monitors pool activity. The video signals feed into a central processor running a machine perception algorithm that can effectively spot when active nonwater objects, such as swimmers, become still for more than a few seconds. When that happens, a red alarm light flashes at a poolside laptop workstation and lifeguards are alerted via waterproof pagers. Last November, a Poseidon system at the Jean Blanchet Aquatic Center in Ancenis, Loire-Atlantique, France, alerted lifeguards in time to rescue a swimmer on the verge of drowning. Pulled from the water unconscious, the swimmer walked away from a hospital the next day.

Similarly, when cell phones and other mobile gadgetry start coming embedded with Global Positioning System transponders, it will be possible to pinpoint the carrier and quickly come to his or her aid, if necessary. Such transponders are already built into many new cars *(see "The Commuter Computer,"* TR *June 2001)*. A click of a button or the triggering of an air bag sends a call to a service center, where agents can then direct emergency personnel to the vehicle, even if the occupants are unconscious. A public ubiquitous surveillance system could also enhance safety by noticing, for example, if a car hits you or if large, unauthorized crowds start congregating around an accident or altercation. As with the car rescue systems, a person's plight could be recognized and help dispatched almost instantly, sort of how air bags are now immediately deployed on impact.

And not many argue about surveillance's ability to deter crime. Recent British government reports cite closed-circuit TV as a major reason for declining crime rates. After these systems were put in place, the town of Berwick reported that burglaries fell by 69 percent; in Northampton overall crime decreased by 57 percent; and in Glasgow, Scotland, crime slumped by 68 percent. Public reaction in England has been mixed, but many embrace the technology. "I am prepared to exchange a small/negligible amount of privacy loss so I don't have to be caught up in yet another bomb blast/bomb scare," wrote one London computer programmer in an online discussion of the technology.

Do the developers of this controversial technology weigh the pros and cons of their creations? Robert Collins of Carnegie Mellon concedes that much of the work that might fall into the surveillance category conjures an Orwellian quease, but he joins a veritable chorus of colleagues who say it's not their station to be gatekeepers looking out for how the technology ultimately is used. "We who are working on this are not so interested in applying it to surveillance and Big Brother stuff," Collins says. "We're making computers that can interact with people better." Indeed, Collins notes that he and his colleagues are motivated by the notion of "pervasive computing," in which the techno-environment becomes aware of its human occupants so that computers and other gadgets can adjust to human needs. The way it is now, he says, humans have to accommodate the limitations of machines.

Technology That Watches

COMPANY	LOCATION	TECHNOLOGY
DIGITAL ANGEL	South Saint Paul, MN	Identity verification and remote-monitoring system for children, pets and seniors. Wristband sensor monitors pulse, body temperature and blood oxygen levels, as well as wearer's location.
VIISAGE TECHNOLOGY	Littleton, MA	Surveillance camera and face recognition system that identifies and extracts key facial features and compares them to those stored in a database.
SARNOFF	Princeton, NJ	Camera and software technology that identifies people through the striation, speckles and patterns of color in their irises.
POSEIDON TECHNOLOGIES	Boulogne, France	Swimming-pool monitoring technology that distinguishes nonwater entities such as people or pets and sends an alert when they become still for too long.
VISIONICS	Jersey City, NJ	FaceIt software extracts facial images from live video feeds for storage in databases or smart cards, or for comparison with existing faceprint files.
IRIDIAN TECHNOLOGIES	Moorestown, NJ	Iris recognition technology that includes Authenticam, a desktop camera that reads the patterns in the iris from up to 48 centimeters away to authorize network access.
ADVANCED BIOMETRICS	Puyallup, WA	LiveGrip, technology that uses infrared photographs of hands as identifiers.
ADVANCED PRECISION TECHNOLOGY	Livermore, CA	HoloPass, holographic-image processing technology for fingerprint identification.

Jonathon Philips, manager of DARPA's Human ID at a Distance program, puts it another way: "We develop the technology. The policy and how you implement them is not my province."

So who is watching the gate? Well, the courts are slowly getting involved. A U.S. Supreme Court decision last June determined that in the absence of a search warrant, the government's use of a thermal imaging device to monitor heat coming off the walls of a suspected marijuana grower's private residence in Florence, OR, violated the Fourth Amendment prohibition against "unreasonable searches and seizures." The ruling could have far-reaching consequences for how new, more powerful surveillance technologies can be deployed. Overall, however, the responsibility of surveillance technology management and regulation is up for grabs in the United States, even as the technology proliferates. And so whether society goes Orwellian or not could well hinge on how responsibly the databases, biometric details and all the rest are managed and protected. After all, notes the ACLU's Steinhardt, it's a small step from a technological advance to a technology abuse.

Take the fact that the faces of a large portion of the driving population are becoming digitized by motor vehicles agencies and placed into databases, says Steinhardt. It isn't much of a stretch to extend the system to a Big Brother-like nationwide identification and tracking network. Or consider that the Electoral Commission of Uganda has retained Viisage Technology to implement a "turnkey face recognition system" capable of enrolling 10 million voter registrants within 60 days. By generating a database containing the faceprint of every one of the country's registered voters—and combining it with algorithms able to scour all 10 million images within six seconds to find a match—the commission hopes to reduce voter registration fraud. But once such a database is compiled, notes John Woodward, a former CIA operations officer who managed spies in several Asian countries and who's now an analyst with the Rand Corporation, it could be employed for tracking and apprehending known or suspected political foes. Woodward calls that "function creep."

Function creep is where things get really dicey for privacy advocates. Several grass-roots efforts now under way seek to rein in surveillance technology through more responsible privacy legislation. The Privacy Coalition, a nonpartisan collection of consumer, civil liberties, labor and family-based groups, is trying to get federal and state lawmakers to commit to its "Privacy Pledge," which contains, among other things, a vow to develop independent oversight of public surveillance technology and limit the collection of personal data. And several organizations, including the AFL-CIO, Communications Workers of America, 9to5, National Association of Working Women and the United Auto Workers, are supporting legislation to restrict electronic monitoring of employees. As Steinhardt declares, "We can't leave this to systems designers or the marketplace."

In spite of these broad efforts, a number of factors, not the least of which is disagreement in Washington about what form such legislation should take, are making it difficult to put words into action. Last year Congress debated the Notice of Electronic Monitoring Act, which would have required companies to notify employees if they were being watched. Although that legislation died in committee, it will probably resurface again this year. As far as individual state laws are concerned, only Connecticut requires employers to tell employees if they are being monitored.

Which leads to the question of what exactly constitutes "private" activity. As former spymaster Woodward observes, a total-surveillance society will not actually expose individuals that much more than ordinary public circulation does now. "Once you leave your house and enter public spaces," he says, "just about everyone you can see can see you right back." In other words, you do not walk around most of the day with an expectation of privacy. Your face is not private, so if a camera sees you, it's no big deal. What's more, asks Woodward, even if rich and powerful entities, such as the government or megacorporations, had sole access to a system capable of watching everyone all of the time, why would they bother? "The bottom line is that most of us are very boring. We flatter ourselves to think that someone is building a multibillion-dollar system to watch us," he says.

A U.S. SUPREME COURT DECISION LAST JUNE SAID THAT THE GOVERNMENT'S USE OF A THERMAL IMAGING DEVICE TO MONITOR A SUSPECTED MARIJUANA GROWER'S PRIVATE RESIDENCE VIOLATED THE FOURTH AMENDMENT.

Even if public opinion does manage to slow down the deployment of surveillance infrastructure, no one involved in the debate thinks it will stop some form of Big Brother from arriving eventually. In his 1998 book *The Transparent Society*, which is well known in the privacy advocacy community, science fiction author and technology watcher David Brin argues that society inevitably will have to choose between two versions of ubiquitous surveillance: in one, only the rich and powerful use and control the system to their own advantage; in the second, more democratic future, the watchers can also be watched. Brin concedes that the latter version would mean everybody's laundry hung out in public view, but the transparency would at least be mutual. Rent a porn video and your wife knows it; but if she drives to your best buddy's house four times a week while you're at the office, you'll know that also.

Whether or not the coming era of total surveillance fits neatly into one of Brin's scenarios will be determined by a complex equation encompassing technological development and the decisions that local, state and federal governments choose to make. The question largely boils down to this: is privacy a right or a privilege? Most Americans assume it is a right, as in our "right to privacy." But the truth of the matter is that privacy isn't guaranteed by the Constitution. It is implied, certainly, but not assured. This subtle difference is being tested right now, within our own neighborhoods and workplaces. TR

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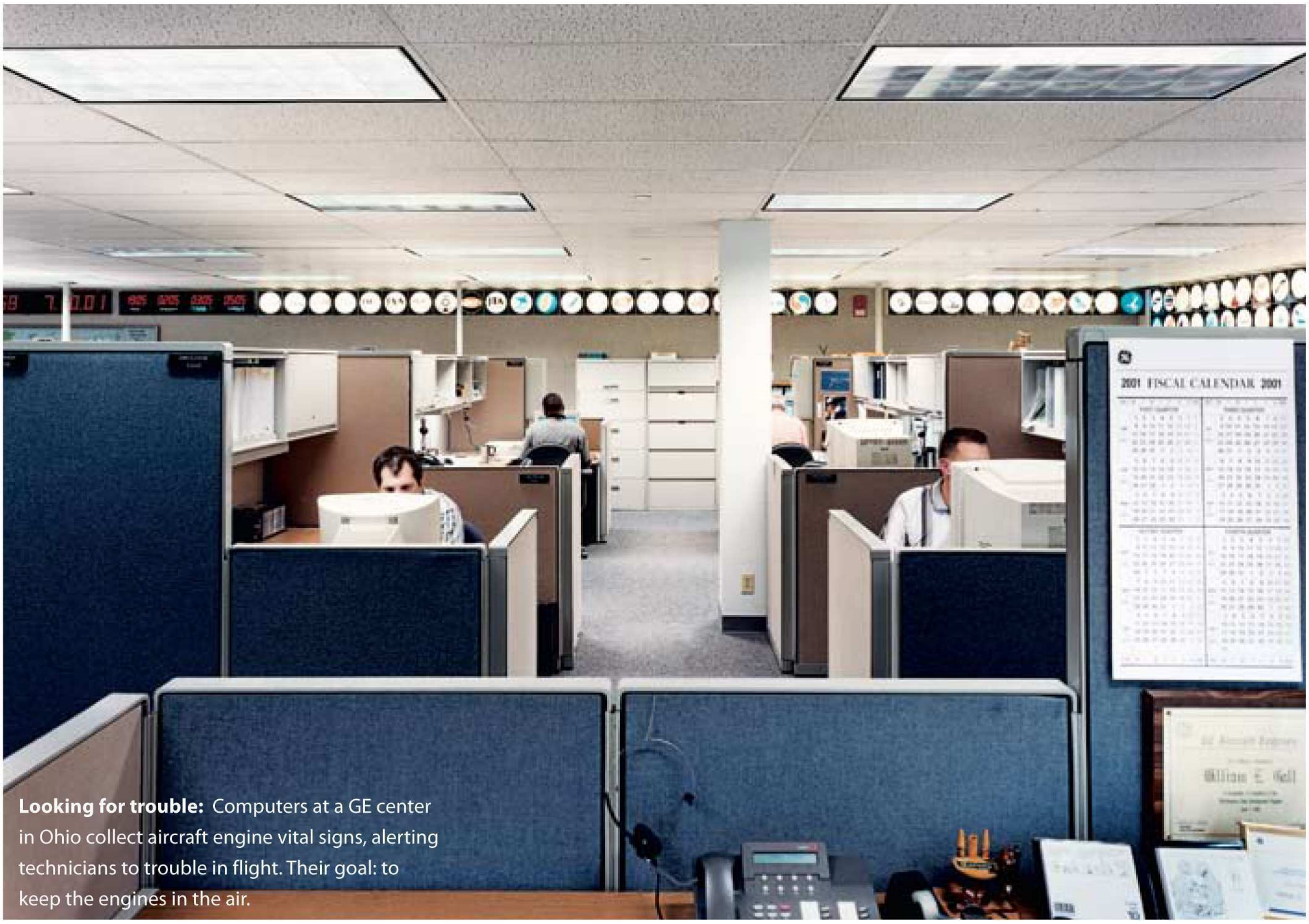
Engine trouble: Somewhere in this jet engine's mass of machinery lies a flaw. GE's intelligent diagnostic systems will find it.

IF IT AIN'T BROKE, FIX IT

COMPLEX SYSTEMS FORESHADOW THEIR FAILURE WITH SUBTLE CHANGES IN PERFORMANCE. HERE'S HOW GENERAL ELECTRIC—THE UNDISPUTED CHAMPION OF REMOTE DIAGNOSTICS—IS USING SENSORS, COMPUTERS AND STATISTICS TO KEEP THE MACHINERY HUMMING. BY ROBERT POOL PHOTOGRAPHS BY RAIMUND KOCH



Looking for trouble: Computers at a GE center in Ohio collect aircraft engine vital signs, alerting technicians to trouble in flight. Their goal: to keep the engines in the air.

THE AIRBUS 340 IS AN HOUR OR SO INTO ITS 11-HOUR FLIGHT from Hong Kong to Auckland, New Zealand. Twelve kilometers below, the islands of the Philippine archipelago are sliding by off to starboard. That's when, deep inside one of the plane's four General Electric-made engines, small bits of insulating skin begin to peel off and fly out the back. Their departure breaches the surface and opens tiny passageways into the compartment where the jet fuel burns. As cold outdoor air seeps in, the compartment's temperature starts to drop.

In the cockpit, the pilots are aware of none of this—the deviations are still too small to show on their instruments. But the event has not gone unnoted. For starters, a thermocouple in the engine compartment has recorded the slightly depressed temperature. Then, three hours into the flight, the onboard computer that has been collecting readings from the engines uploads the data to a satellite, which relays the information at light speed to a computer in Glendale, OH, just north of Cincinnati. This machine notices the temperature anomaly, and after taking into account other sensor readings, as well as details about the particular engine's maintenance history, correctly identifies the likely cause: delamination of the skin covering the engine's thrust reverser. The situation poses no immediate danger to the aircraft. But the airline is notified by telephone, and when the plane arrives in Auckland, mechanics are waiting with the parts needed to repair the skin. They finish in time for the aircraft to leave as scheduled on its next flight.

Five years ago, this could not have happened. The delamination would have worsened gradually, flight after flight, until a mechanic noticed it in the course of a visual inspection. By that point, it would have required extensive and expensive repairs that would probably have forced the delay or even cancellation of the aircraft's next flight and possibly kept it out of service for days or weeks. But today, thanks in large part to sophisticated new statistical techniques that make it possible to detect previously invisible patterns in data, remote monitoring and diagnostic devices are able to spot many problems as soon as they occur—and sometimes even before. "Doctors talk about people in the future walking around with heart-monitoring devices that will give advance warning of heart attacks and other problems," says Gerald Hahn, the recently retired founder and manager of General Electric's Applied Statistics Program in Schenectady, NY. But with complex machinery like aircraft engines and locomotives, he says, "we're already there."

To date, remote monitoring has been applied mainly to big-ticket items where unexpected breakdowns can cost a company tens or hundreds of thousands of dollars. "In the next few years, remote monitoring will be included in the majority of car models," says Laurence Fourchet, an analyst with the market research company Frost and Sullivan. The promise, she says, is the same that has driven airlines and railroads to install the systems: to sniff out clues that a system is heading for a failure so that preventative action can be taken. Ideally, Fourchet explains, "someone will tell you that sometime in the next few days you need to check the engine—before the breakdown occurs."

This trend toward self-diagnosing systems appears headed for even greater ubiquity, as efforts are already under way to develop similar capabilities for household appliances like refrigerators, washers and dryers. In the not-too-distant future, an engineered world studded with sensors, computing chips and communications ports, and embedded with sophisticated mathematical tools, could banish the cost and headaches of machine downtime.

JUST-IN-TIME MAINTENANCE

There is nothing new about sticking monitors into machines to notice when some variable wanders outside its normal range. The temperature gauge that's been in automobiles for decades is one simple example—the mechanical equivalent of having patients walk around with thermometers in their mouths.

But the remote monitoring emerging today is of a different magnitude altogether. Think of strapping several dozen monitoring tools onto the patient—blood pressure and heart rate, electrocardiogram, brain wave sensor and more, with the doctor following the data remotely, analyzing it with reference to each patient's medical history, and then offering regular diagnoses that might include advice on when to pop an aspirin before a headache even occurs. That is the sort of continuous checkup that is now becoming practical for sophisticated machinery.

The value of such supercharged monitoring is obvious to anyone who has ever missed a meeting because a flight was canceled or lost electricity because some part in a utility substation broke. Catching problems early means less expensive repairs, less downtime and less disruption of service and schedules. At the same time, knowing what is going on inside an engine or other piece of equipment can provide the confidence to hold off on a replacement or repair until it is necessary. The ultimate goal is just-in-time maintenance—knowing exactly what repairs to make and when. "There are two kinds of mistakes—replacing too soon, and replacing too late," Hahn says. "We want to minimize both."

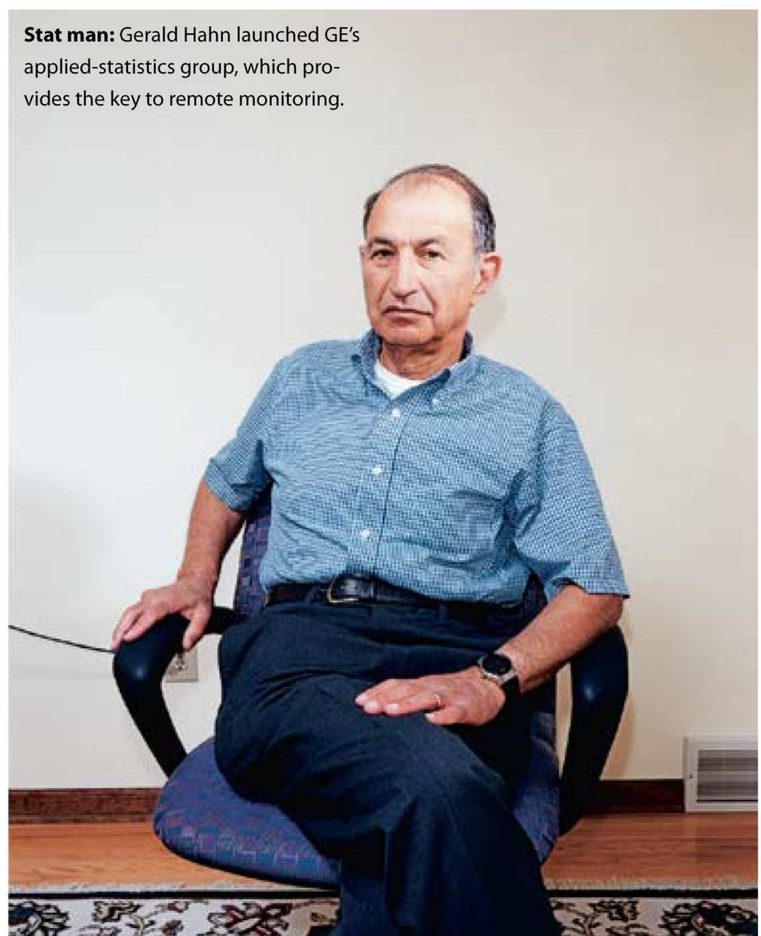
Many companies have been designing and building equipment so that its health can be monitored during operation. Asea Brown Boveri, the giant European industrial conglomerate, puts remote-diagnostics capability into the propulsion systems it makes for cruise ships and other large vessels; an onboard computer collects operating data and forwards it via satellite to Helsinki for analysis. Turbine Technology Services operates a facility in Orlando, FL, that remotely monitors data from the turbines used in power plants. Other firms monitor the performance of computer equipment such as servers and routers, while the heating, ventilation and air-conditioning systems in many large buildings are equipped with devices that allow engineers to spot problems by observing such variables as airflow and temperature.

But perhaps no company has done more work in these areas than General Electric. A diversified conglomerate with some two dozen divisions, GE manufactures complex industrial equipment—power turbines and ship propulsion systems, in addition to aircraft engines and locomotives—alongside consumer items such as appliances and lighting products. GE is at the forefront of remote monitoring and diagnostics in a variety of fields, says Nick Heyman, an analyst at Prudential Securities who follows the company. Heyman points specifically to GE's leadership in monitoring of aircraft engines; it was a GE monitoring station outside Cincinnati that spotted the delamination in the engine of the Auckland-bound Airbus. Other GE facilities keep an eye on locomotives, merchant-ship engines, gas turbines and medical imaging devices. The company's applied-statistics program, founded in 1975 at the corporate R&D center in Schenectady, has grown to be one of the world's most respected groups in that discipline, and it has provided the ammunition for several GE divisions to develop remote monitoring and diagnostics capabilities. The developments at GE therefore offer a case study of how remote monitoring and diagnostics is transforming the way that complex technological systems are kept in top working condition.

Figuring out from afar what's wrong with a piece of complex machinery entails two separate but related functions. One is to detect anomalies as soon as they appear; that's what happened with the Airbus. Complementing that is the forecasting of problems before they even arise. Both capabilities have improved tremendously over the past few years—thanks, Hahn says, to a convergence of three very different advances. One is the development of smaller, lighter-weight sensors. Second is the tremendous growth in computing power. Third—and perhaps most important—is the emergence of new statistical techniques that allow researchers to distill useful information from mountains of data.

On the sensor front, much of the progress can be traced to the same sorts of processing advances that have shrunk computer chips so remarkably over the past 20 years. Another factor is also at play, says Larry Abernathy, head of the diagnostics engineering team at GE Engine Services in Evendale, OH. That is the trend to replace mechanical controls with electronic ones that make it much easier to gather data. For example, today's "fly-by-wire" jets are controlled by dozens of computers that know precisely what is going on in the various systems that they command.

But getting the relevant data is rarely the whole battle. Knowing what to make of it is often the difficult part, and it is here that the other two advances—in computing and statistical analysis—come into play. Consider, for example, the challenge of figuring out what part or system might need attention on a 200,000-kilogram locomotive. Although trains may be commonly perceived as relics



Stat man: Gerald Hahn launched GE's applied-statistics group, which provides the key to remote monitoring.

from the 19th century, modern locomotives are relentlessly high tech. "Think of them as rolling power plants," says Joe Cermak, leader of the Remote Maintenance and Diagnostics Center of Excellence at GE's Transportation Systems division in Erie, PA. The AC6000, GE's newest and most powerful locomotive, boasts a 6,000-horsepower, turbocharged, fuel-injected diesel engine that spins an alternator to generate some four megawatts of electric power. That's enough electricity to run 3,000 homes, but here it drives six independent traction engines that give the locomotive enough oomph to pull 100 cars at up to 120 kilometers per hour.

Two dozen microprocessors control the locomotive, allowing the entire operation to be directed by a single engineer sitting before a computer console in the locomotive's cab. Sensors monitor nearly every variable of interest, from the locomotive's speed and horsepower output to the voltages, torques and speeds of the individual traction motors to the battery voltage and current. All of this information is collected at GE's service center in Erie, PA, where about 50 technicians and engineers monitor nearly 300 locomotives belonging to a major U.S. railroad.

Much of this information was available in some form 20 years ago. The difference now is its accessibility for analytical purposes. "We used to have data stored in file cabinets," Hahn remembers. To make sense of the data required manually entering it into a computer. Even then, the computers were not fast enough to sift through more than a fraction of the information in a reasonable amount of time. As a result, it was very difficult to spot any but the most obvious problems.

Now that has changed. As Jason Dean, a systems engineer with GE's Remote Monitoring and Diagnostics group, explains, even something as seemingly simple as spotting a clogged fuel filter was hit-or-miss. A stopped-up filter can cut a locomotive's horsepower by 20 to 30 percent. That's a deficit small enough to go unnoticed when the load is light, but one that can slow the train considerably when it is hauling many cars or heading up an incline. And one slow train can back up the entire rail network.

Diagnosing this malfunction is not straightforward. The major indication that a filter is plugged is increased fuel usage, Dean says. But other factors—such as air temperature, the horsepower being produced and the train's speed—can cause fuel usage to vary by as much as 20 percent, and so the engineer who sees a drop in efficiency cannot know from that alone what's at the root of the problem. The solution, in theory, is simple: collect historical data on each locomotive's operations and apply statistical analysis to create a model of the train's performance. If fuel usage jumps significantly above what the model predicts for a particular set of conditions, the fuel filter should be replaced.

EMBRACING THE DATA

The feeble computers of the past were not up to this job, though. "Years ago," Abernathy says, "we would see a shift in the data, and we would try to handle it using three or four or five parameters." Engineers would make educated guesses as to which were the most important variables—the train's speed, say, and the ambient temperature—and then perform a regression analysis (a standard technique that teases out the effects of different factors on a variable). But no matter how carefully the parameters were chosen or the calculations performed, the model's predictions were inevitably impaired by the limitation on how much the computer could handle.

Today's technology has removed that limitation. Twenty years ago, statisticians spent a great deal of effort finding clever ways to limit data and still get reasonable answers. Now, empowered with faster number-crunching machines, they embrace the data. "We can look at tens or hundreds of parameters, and we can determine relationships that we could never see before," Abernathy says. Picking out subtle relationships between variables in operating conditions and in system performance is important, because

Tracking the trains: Microprocessor-studded locomotives relay sensor data via satellite for display at a GE service center.

COURTESY OF GE TRANSPORTATION SYSTEMS

those relationships, if they are not accounted for, can cause the model to spit out inaccurate results.

Here is where the third key advance—in statistics—comes into play. Statisticians have developed a number of analytical tools that take advantage of this increased computing power to create more accurate projections than are possible with classical regression analysis. Among the most important is a technique using predictive models called "decision trees," or, more particularly, "classification and regression trees." This method is well suited for such tasks as predicting whether a locomotive engine will fail on a given outing. It does not assume, as regression analysis does, that the relationship between the input variables (age, distance traveled, operating temperature, oil pressure and so on) and the output variable (whether the machine fails or not) is a matter of simple extrapolation. Given enough data, a decision tree can model virtually any relationship, no matter how complex. It can also handle incomplete data—such as readings made when a sensor is malfunctioning—much more easily than can regression analysis. And whereas regression analysis generally reaches a point of diminishing returns, past which gathering more data will not improve the predictions, that's not the case with decision trees. With the new method, "more data is always better," says Jerome Friedman of Stanford University, one of its developers.

The decision tree works, Friedman explains, by dividing a set of data into smaller and smaller partitions until it reaches a best partition for predicting a particular outcome. The data might, for example, consist of thousands of sets of readings made on hundreds of locomotive engines. The outcome in question might be whether a given engine will run smoothly for another 5,000 kilometers. The best indicator of whether an engine will fail might be whether its current operating temperature is above or below a certain level, or perhaps whether it has covered more or less than a certain distance since its last major overhaul. The decision tree begins by slicing the data into the two subsets that best correlate with the two divergent outcomes. Each of the resulting two subsets of data points is then split by the same best-prediction criterion; the resulting four subsets are divided; and so on, until further divisions do not improve the predictive value.

Thanks to such statistical tools, people like GE's Abernathy can wring an astonishing amount of information from the signals trickling out of the sensors on technological devices. Jet engines cost between $5 million and $10 million and need an overhaul every three to five years. Because this procedure is also expensive—costing $500,000 to $2 million—airlines strive to maximize the time between one overhaul and the next. An equally important goal is to avoid having too many engines due for major servicing at the same time: airlines have only so many spares on hand.

An overhaul is dictated by one of three factors. The easiest factor to predict is called "life limits on parts." The Federal Aviation Administration demands that certain critical components be replaced after a given number of flights or flight-hours. About one-third of engine removals are due to this, says Rusty Irving, head of GE's information technology lab in Niskayuna, NY. Another third occur because the exhaust gas temperature of the engine has risen too high—an indication that parts are wearing out and forcing the engine to run hotter to create the same thrust. The rest of the removals stem from a variety of hardware problems, such as a bird or other foreign object being sucked into the engine, or a leak or crack that exceeds some predefined limit.

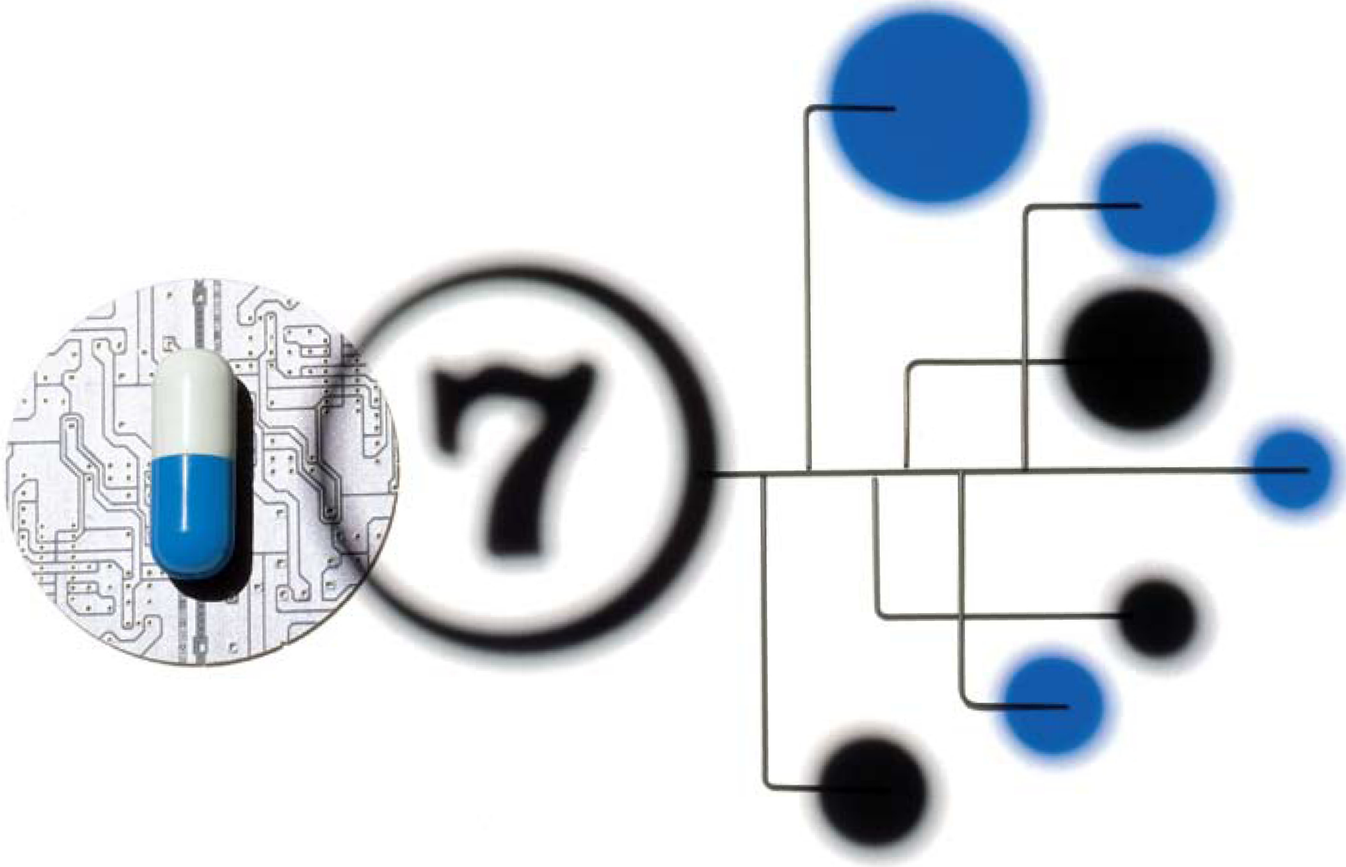
The ability to forecast when engines need servicing would allow the company to plan how many spare engines it needs to have on hand at any given time. But in the past, Abernathy says, techniques to predict when an engine would need servicing were little more than blunt tools. The statisticians could figure how soon the typical life limits on parts would force a given engine to be overhauled. They could also calculate how rapidly the exhaust gas temperature increased on average for all the planes in a fleet, which gave a rough indication of how soon an engine might have to come off for that reason. "Then we'd throw in 20 or 30 engines on top of that"—to account for removals due to hardware problems—"and that was our number," Abernathy explains.

This would work fine if every engine behaved like an average engine. In reality, though, Abernathy says, engine deterioration rates can vary tremendously. The new statistical tools allow GE Engine Services to predict when each individual engine is likely to need an overhaul, then combine those forecasts to create a month-by-month projection of how many engines will be sent in for repair. And, he adds, because the statistical tools also predict why each engine will need servicing, "we can even predict the turn times"—that is, how long each engine will be in the shop. This enables the airline to look a year or more into the future and see how many engines are likely to be "off wing" at any one time. If one month looks to have more than its share, the airline may opt to move up some of the anticipated overhauls to lessen the need for spares and lower the demand on the overhaul center.

ULTIMATELY, IMPROVEMENTS AND COST REDUCTIONS IN SENSORS AND COMPUTING POWER WILL ENABLE REMOTE MAINTENANCE AND DIAGNOSTICS TO MOVE TO CONSUMER PRODUCTS. REFRIGERATORS, WASHERS AND OTHER APPLIANCES WILL RECEIVE INSTRUCTIONS AND REPORT OPERATING CONDITIONS OVER THE INTERNET.

Ultimately, improvements and cost reductions in sensors and computing power will enable remote monitoring and diagnosis to move to smaller items, including consumer products. Major carmakers are already working on systems that will spot and report maintenance problems in cars. At GE, the appliance division is developing refrigerators, washers and other machines that can receive instructions and report operating conditions over the Internet, while Whirlpool, Bosch, Samsung, IBM, Cisco Systems, Microsoft and other companies are working on standards and designs for a variety of Internet-enabled appliances.

One idea under consideration is to build appliances capable of making their own service appointments before their owners even recognize something is wrong. If, for instance, an oven uses too much electricity to achieve the desired temperature, it might alert a service center that the heating element is close to breakdown. Engineers say the major hurdle to realizing that scenario is not technical but psychological: getting people used to the idea of a repairman ringing the doorbell and announcing, "The oven asked me to come." TR



7 STARTUPS GRADUATE WITH HONORS

Say hello to some of the hottest young companies ushering university research to the marketplace

PHOTOGRAPH Pierre-Yves Goavec

TRACE ALMOST ANY IMPORTANT NEW TECHnology back to its roots and you're more than likely to find a university research lab. But even the most stunning academic innovation—a breakthrough anticancer compound or a completely novel type of computer chip—will have little impact on our world and our lives unless it makes its way out of the lab and into the marketplace. That journey often begins with the launch of a brand new company, so the editors of *Technology Review* set out to find seven of the most intriguing such startups. You'll meet them when you turn the page.

The selection of these seven startups is the culmination of a months-long search. We sought out the most original and promising companies formed in the last few years to commercialize inventions from university labs around the world. We consulted with university technology managers, prominent researchers, venture capitalists and key industry observers to choose fledgling firms—in areas ranging from computer chips to drug discovery—that we believe not only have something new and important to contribute but that also stand a good chance of making it in the business world. There are, of course, no guarantees of success, but of the hundreds of companies we considered, these stand as the stars.

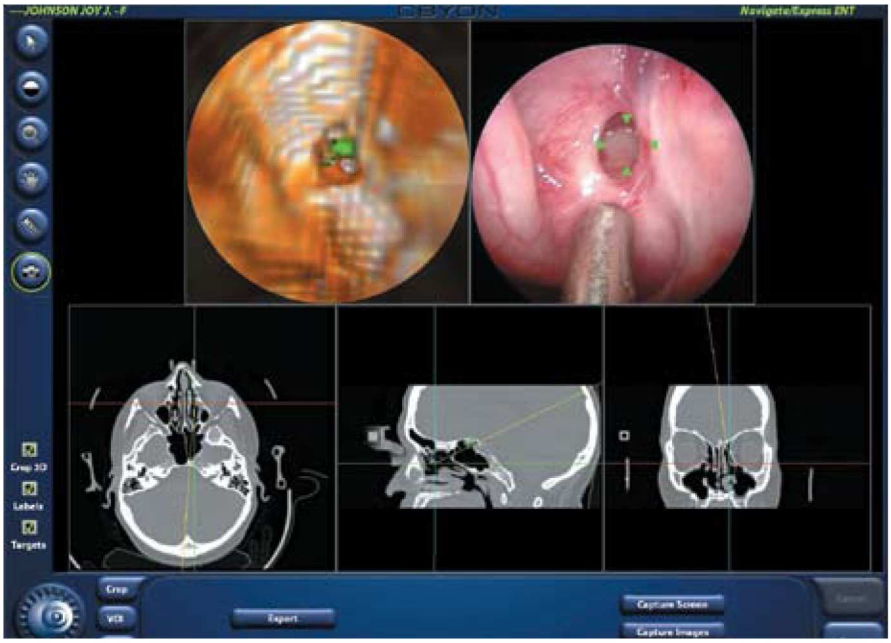
Still, not every new university technology heads to market under the steam of its own startup. Indeed, most universities take the more traditional route of licensing their new technologies to outside corporations. That's why we haven't stopped at startups. In the *TR* University Research Scorecard on page 81, we reveal which U.S. universities are doing the best job of patenting and licensing the fruits of their research labs, using data from CHI Research in Haddon Heights, NJ, and from the Association of University Technology Managers in Northbrook, IL. The accompanying analysis of the scorecard highlights the important trends behind those numbers.

Taken together, these stories will give you a snapshot of university innovation today—and a sneak preview of technology tomorrow.

CBYON

UNIVERSITY	Stanford University
FOUNDED	February 1999
TECHNOLOGY	3-D surgical software

STORY Rebecca Zacks / PHOTOGRAPH Cbyon



In Cbyon's system, a camera shows a surgical probe in a patient's sinus (top right). Green arrows mark a nerve behind the sinus wall, located by matching the image to a 3-D digital model (top left) showing the nerve in green. Cross hairs on three 2-D views (bottom) mark the probe's tip.

SAY YOU'RE ONE OF THE ROUGHLY 300,000 Americans who will need sinus surgery this year. The good news is the surgeon probably won't have to make any incisions on your face; instead, he or she can thread a video-camera-equipped tube called an endoscope through your nose into the ailing sinus, then pass the surgical tools through the tube. The bad news is that even with the help of the camera, the surgeon can't see your optic nerve lying just behind the sinus wall—and damage to the nerve could mean blindness in one eye. It's a rare complication, but just the sort of disaster that Palo Alto, CA-based Cbyon would like to help avoid. The company's 3-D visualization software shows a surgeon not only where each instrument is, but also what important structures—nerves, blood vessels, tumors—lie hidden nearby.

The software is the brainchild of Stanford University bioengineer Ramin Shahidi, who has taken leave from the institution to serve as chief technology officer of Cbyon, which he helped found in February 1999. Using data from x-rays, MRI images, ultrasound and other scans, Shahidi's software builds a digital model of the patient's anatomy. During surgery, a computer tracks the position of the surgical tools in relation to the digital model and displays that information on a screen. Up to this point, the Cbyon system is similar to other products for image-guided surgery that have been on the market for years. But where those systems usually display a set of two-dimensional slices that a surgeon must mentally translate into a three-dimensional object, Cbyon's software offers what's called "3-D perspective volumetric rendering"—a visualization technique that gives the surgeon a realistic 3-D anatomical model. That image can match the camera's perspective in real time and reveal critical structures that the camera *can't* see—the optic nerve, for example—by marking them with bright colors and making the overlying tissues transparent. Shahidi can't resist calling it "Superman 3-D x-ray vision."

Now 50 people strong and banking more than $20 million in venture capital and other financing, Cbyon has already gained U.S. Food and Drug Administration approval to market its technology for a number of applications, including neurosurgery and ear, nose and throat procedures. For $120,000 to $150,000, a hospital can buy a complete package that includes the 3-D software along with a computer, a monitor and equipment that tracks surgical tools during an operation. The startup hopes its 3-D advantage will help it capture a healthy share of the fast growing $270 million market for such image-guided surgery systems.

But even with a visualization component that is without question the best available, says Saint Louis University School of Medicine surgeon Richard Bucholz, Cbyon could face tough challenges in the marketplace. Bucholz, who developed one of the first and most widely used image-guided surgery systems—now sold by Medtronic of Minneapolis, MN—points to at least two other companies that make diagnostic tools that incorporate 3-D rendering software similar to Cbyon's. That software could readily be adapted to a surgical guidance system.

Furthermore, says Bucholz, doctors will not adopt Cbyon's core software technology if they don't like the hardware that comes with it, or if it's not compatible with favorite image-guided surgery components that they have already. "Surgeons have very strong preferences for particular units—a surgeon likes this type of scalpel, she likes that type of ultrasound device, this type of clamp—and the same desires are going to be made vis-à-vis the components of the operating room of the future," he says.

The son of an eye surgeon, Shahidi is well aware of how important ergonomic details and preferences are to a surgeon. When his father saw a demo of the Cbyon system, says Shahidi, "The first thing he told me was 'Your cart is too big,' so immediately we went and reduced the size." Continuing to seek and heed such feedback will likely be critical to the company's future, and to determining whether Cbyon can help make thousands of surgeries a year a little bit safer.

Others in Image-Guided Surgery

COMPANY	Medtronic
LOCATION	Minneapolis, MN
TECHNOLOGY	StealthStation system
COMPANY	BrainLAB
LOCATION	Heimstetten, Germany
TECHNOLOGY	VectorVision system

IMPINJ

UNIVERSITY	University of Washington/Caltech
FOUNDED	April 2000
TECHNOLOGY	Adaptive computing

STORY Susan Borden / PHOTOGRAPH Karen Moscowitz

IMAGINE A CELL PHONE THAT NEVER RUNS OUT of juice and delivers crystal-clear reception, or an inexpensive handheld computer that can get loads of information off the Web without running out of memory. Don't start queuing up yet, but the radically new microchips that could make such devices possible are being pieced together even as you read this magazine. And for one of the most intriguing approaches to making such advanced chips, look no further than Seattle's Impinj.

Founded last year, Impinj ventures onto the microchip scene with an impressive lineage. Caltech engineer Carver Mead, one of the cofounders, is a near legendary chip-design pioneer who has 21 previous startups under his belt and consulted for Intel in its early days. University of Washington computer scientist Chris Diorio, the company's chairman and cofounder, did his graduate work with Mead. Diorio's work on computers that mimic the nervous system won a Presidential Early Career Award, among other prestigious grants. And that work also sparked the technology that is central to Impinj's innovative chips: a silicon transistor that can adapt to its environment, recalibrating itself on the fly in response to changing signal quality or a device's new needs.

The Lilliputian transistors on today's computer chips are perfectly suited to processing digital information, says CEO William Colleran. They turn on and off like a light switch to represent the zeroes and ones of a digital signal. But a device like a cell phone must process analog signals as well—the sound of your voice picked up by the microphone, for example—which consist of continuous waves rather than discrete pieces of information. As a result, such devices must include additional, larger transistors for processing analog signals and converting them to a digital format—taking up space, adding to power demands and making the devices more expensive to produce. Impinj's solution? A digital-sized transistor that can process analog signals as easily as it handles ones and zeroes. Colleran calls it "the transistor equivalent of a dimmer switch," able to be on, off or any position in between. What's more, he notes, each transistor can continuously recalibrate its position, allowing the chip to constantly adapt to signal interference, degraded hardware and new tasks. And, as unusual as they are, Impinj's transistors can still be fabricated with standard chipmaking techniques, so manufacturers won't have to retool their factories.

Backed by $15 million from Seattle-based Arch Venture Partners and Madrona Venture Group, Impinj is betting that this "self-adaptive silicon" will improve analog/digital signal processing, while also offering such perks as longer battery life and improved performance. But the real home run, says Gartner Dataquest analyst Stan Bruederle, might be that the chips' flexibility could save manufacturers from having to make a new, highly specialized chip for each new type of device—which requires expensive new templates—as is usually the case today. "Imagine, instead of processing a bunch of different transistors for different devices, you can manufacture one product in high volumes that can be programmed within the various devices later on," Bruederle says. "This is much more cost effective." A handful of other companies have also come out with chips that can be programmed to different tasks *(see table)*, but unlike Impinj's chips, those require a new software upgrade for each shift in function.

For the time being, Mead, Diorio, Colleran and their colleagues are only willing to say they're working on "adaptive communications"—that is, building a better cell phone. However, with all the possibilities opened up by Impinj's approach to chips, industry observers are keeping their eyes peeled for a lot more. "I know these guys," says David Gifford, a professor of electrical engineering and computer science at MIT. "I have no doubt that they have other tricks up their sleeve." When Impinj does decide to show its hand, it could well change the way we think about chips.

Others in Adaptive Computing

COMPANY	Altera
LOCATION	San Jose, CA
TECHNOLOGY	Multipurpose programmable chips
COMPANY	QuickSilver Technology
LOCATION	San Jose, CA
TECHNOLOGY	Programmable chips for wireless devices
COMPANY	Xilinx
LOCATION	San Jose, CA
TECHNOLOGY	Multipurpose programmable chips

Impinj cofounder Chris Diorio has helped develop a microchip that can learn.

PICOPETA SIMPUTERS

UNIVERSITY	Indian Institute of Science
FOUNDED	May 2001
TECHNOLOGY	Affordable computing

STORY Alexandra Stikeman / PHOTOGRAPH Christopher Brown/Corbis Saba

VIJAY CHANDRU PLACES HIS POCKETBOOK-sized computer gently on the table. The computer scientist from the Indian Institute of Science believes this gray box could be the future of personal computing in his country. Costing about the same as a handheld computer, Chandru's "Simputer" has much of a PC's functionality. And if he and his colleagues at PicoPeta Simputers are right, that combination of power and affordability will help make information technology far more accessible in the developing world.

The idea for the cheap and easy-to-use computer got off the ground in early 1999 when Chandru and three of his colleagues at the Indian Institute of Science in Bangalore teamed up with the CEO and two vice presidents from a local software firm to form the nonprofit Simputer Trust. A year and a half later, the Simputer made its debut. The Linux-based device is slightly larger than a Palm but has ten times the processing speed. It can operate in four different languages (three Indian languages and English), play MP3 files, send and receive e-mail, and browse the Web. A touch screen, a graphical interface and a speech synthesis program that reads text aloud could allow nonliterate people to use the computer with ease; while a smart-card system lets multiple users share the device.

The projected cost of the device is less than $200. "I don't know anyone else in the world who is producing a comparable sophisticated computer at this price," says MIT sociologist of science Kenneth Keniston. The low cost is possible, in part, because the inventors relied on a nonproprietary operating system and other free software. Unlike a PC, which might cost four times as much, the computer stores data on an inexpensive "flash" card instead of a hard drive, and it uses a more affordable—albeit slower—processor.

In May, the four trustees from the Indian Institute of Science founded for-profit PicoPeta Simputers to commercialize the new machine. PicoPeta is seeking half a million dollars in angel funding to build and field-test a few hundred prototype Simputers. If these prototypes drum up enough business, PicoPeta will seek $5 million in venture capital to manufacture the machines; the company's aim is to have a marketable product ready by year's end.

The trust also plans to license the technology to any company that wishes to commercialize the Simputer. Firms in developing nations will pay a one-time fee of $25,000 to the trust, and those in industrial nations will pay ten times that. With one billion people living in India, Chandru has few worries about other manufacturers and sees no shortage of customers to keep PicoPeta profitable.

Chandru thinks the Simputer might find its first application in the country's ubiquitous telephone kiosks, since "in India, the average middle-class family won't be able to afford one of these." Each user could swipe his smart card through the machine to retrieve personal information, do banking and send e-mail. Farmers could access market prices online to gain greater negotiating power with middlemen. And health-care workers in remote areas could look up medical information. Already, organizations in India and abroad have expressed interest in using the devices for applications ranging from transportation management to rural banking. Starting next spring, Chandru hopes, his small gray box will become familiar to more and more people in India.

Others in Affordable Computing

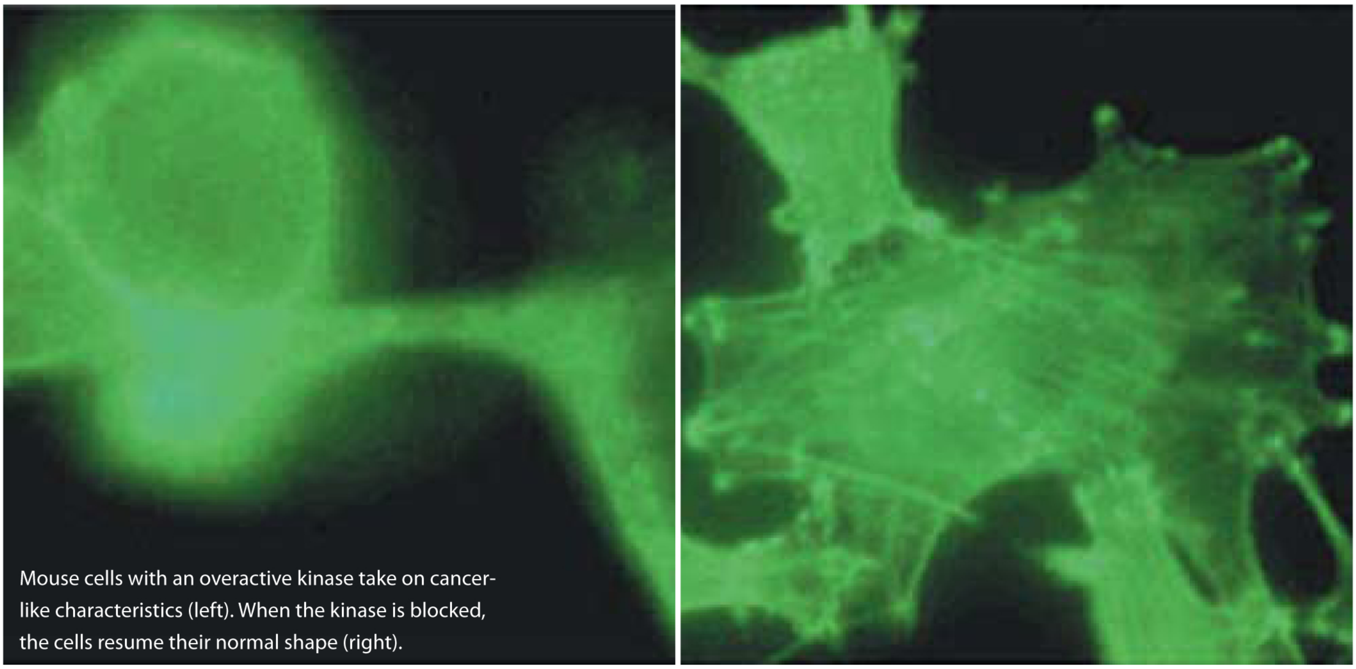
COMPANY	Intel
LOCATION	Santa Clara, CA
TECHNOLOGY	Simple computer for Web access
COMPANY	ThingMagic
LOCATION	Cambridge, MA
TECHNOLOGY	Simple mobile computer

The four founders of PicoPeta Simputers (from left to right, Vijay Chandru, V. Vinay, Ramesh Hariharan and Swami Manohar) and a prototype of their device.

CELLULAR GENOMICS

UNIVERSITY	Yale University/Princeton University
FOUNDED	April 1998
TECHNOLOGY	Kinase-based drug discovery

STORY Erika Jonietz / PHOTOGRAPH Kevan Shokat



Mouse cells with an overactive kinase take on cancer-like characteristics (left). When the kinase is blocked, the cells resume their normal shape (right).

IRA MELLMAN NEVER INTENDED TO START A company. Preparing to leave Yale University for the University of California, San Francisco, a few years ago, the cell biologist went to Yale's Office of Cooperative Research just to get the okay for a research agreement with a drug company. But his work on the immune system so intrigued the staff they talked him into starting a company (and staying at Yale) instead.

Today, Branford, CT-based Cellular Genomics holds a unique set of tools for understanding some of the hottest drug targets around: proteins called kinases. These molecules are critical players not only in the immune system but in everything from cell division to sugar metabolism. The promise of drugs that target these proteins was highlighted this summer when the U.S. Food and Drug Administration approved Gleevec, a drug from Novartis that acts on kinases that go awry in leukemia and stomach cancer. But the problem in pinpointing the kinases involved in arthritis, Parkinson's and other diseases is distinguishing them from the upwards of 500 such proteins in the human body, all chemically similar. What's more, a kinase causing a problem in one part of the body could be vital elsewhere. That's why Cellular Genomics is tackling kinases from all angles, says Mellman, now a scientific advisor to the company. "We're interested in doing whatever needs to get done to evaluate how kinases work."

Cellular Genomics has exclusively licensed two key technologies. The first, developed by Princeton University chemist Kevan Shokat—now at the University of California, San Francisco—inspired the company to zero in on kinases shortly after its 1998 launch. (The company originally licensed Shokat's technology to aid Mellman's immune research but, noting the broader utility of the new tool, relegated that research to a more minor role.) Shokat's system allows researchers, for the first time, to track an individual kinase, seeing which other proteins it interacts with inside the cell, whether blocking it effectively treats a disease, and if side effects could be a problem. The second core technology, the brainchild of Mellman's Yale colleague Henrik Dohlman, extends this tracking ability all the way to kinases and other proteins embedded in the membrane that surrounds the cell.

This one-two punch could help Cellular Genomics pinpoint numerous new kinase-based drug targets. But experts say it won't be easy. "We have been trying to work on [Shokat's technique] ourselves," says biologist Tony Hunter of the Salk Institute in La Jolla, CA. "It's not trivial, necessarily, to get it to work." Still, he says, "Most people see this as a major step forward in analyzing kinase function."

Backed by $26.5 million from health-care venture capital heavyweights like MPM Capital, AGTC Funds and Vector Fund Management, Cellular Genomics thinks it has a shot at turning its kinase-tracking tricks into biotech gold. The company is forging partnerships with drug firms to identify drug targets and test the new medicines its partners develop. Within the next year and a half, though, the company hopes to begin developing its own drugs. As more drug companies home in on kinases as the next big thing, Cellular Genomics could be in the perfect position to help show them the way.

Others in Kinase Biology

COMPANY	Kinexus Bioinformatics
LOCATION	Vancouver, British Columbia
TECHNOLOGY	Tracking kinases using antibodies
COMPANY	Novartis
LOCATION	Basel, Switzerland
TECHNOLOGY	Kinase-based cancer drugs
COMPANY	AstraZeneca
LOCATION	London, England
TECHNOLOGY	Kinase-based cancer drugs

SPHERE SOFTWARE

UNIVERSITY	Johns Hopkins University
FOUNDED	April 2000
TECHNOLOGY	Data/network management

STORY Alexandra Stikeman / PHOTOGRAPH Chris Hartlove

Sphere Software CEO David Glock is looking to help banks, law firms and health-care organizations get a better handle on their databases and networks.

AS COMPANIES FROM BANKS TO BUTCHERS' shops become dependent on their computer databases—and increasingly vulnerable to hackers and overly curious employees—the ability to control the flow of information in company networks is at a premium. Today's network software can do part of the job, password-protecting specific files, for example, or blocking outsiders' access to the corporate network, but it's usually an all-or-nothing proposition. What if, for example, a bank teller needs access to a customer's old address, but that information is restricted because it's in a document that also contains confidential credit information? Columbia, MD's Sphere Software is using technology licensed from Johns Hopkins University's Applied Physics Laboratory to build software that will not only keep data secure but will also make sure everybody in the company can get the information they need.

In April 2000, CEO David Glock, a 17-year veteran of the Applied Physics Lab, started Sphere Software with two key technologies from the lab: an advanced search engine created by software engineer James Mayfield and a network-monitoring tool developed by his colleague Sue Lee. Mayfield's technology can go beyond simple database searching to sift through huge numbers of different types of files, extract all the relevant information—and weed out anything a particular user isn't meant to see. Lee's software uses artificial intelligence to keep watch over network traffic, learning the normal pattern of data flow and picking up on any irregularities. That gives the software the ability, not only to catch hackers and snoops, but also to keep track of the day-to-day operations of an organization. In a hospital, for instance, the software could become familiar with doctors' prescribing habits. If one week a doctor prescribes more morphine than usual, it could detect the change and alert an administrator.

One reason that Sphere's system can promise to do so much is that it takes advantage of a data format called XML. A descendant of the familiar Web language HTML, this format is only a few years old but is rapidly finding applications far beyond the Web. That's because it allows a user to attach a descriptive "tag" to a piece of data, essentially saying, "this is a name," or "this is a phone number," or even "this is confidential." These tags help Sphere's software hunt not just for keywords but for different types of information, skipping over data that is useless or forbidden to a particular user.

Even backers of Sphere, however, acknowledge that the system's requirement that an organization's data be in the XML format could initially be a hindrance. Widespread adoption of Sphere's software won't happen until the format establishes itself as a standard, says Andrew Clark, president of Wheatfield Ventures, a private equity fund in Columbia, MD, that will be providing some of the $500,000 that Sphere hopes to raise by the end of this month. Still, says IDC analyst Susan Feldman, XML-based software is increasingly in demand. "I think combining artificial intelligence and XML technologies is a great idea," Feldman says.

This summer, Sphere unveiled a free, skeleton version of its software—lacking Mayfield's and Lee's components—that can do very simple tasks such as authenticating requests for documents. As of July, Sphere's nine employees were working with half a dozen engineers at the Applied Physics Lab to turn Mayfield's and Lee's technologies into independent modules that could plug into the skeleton program. Sphere plans to sell those modules, along with a tool kit that lets users further tailor the program to their organizations' needs, beginning this fall. If all goes according to plan, Sphere's software could soon begin to transform the way we protect our data—and the way we put it to use.

Others in Database and Network Management

COMPANY	Microsoft
LOCATION	Redmond, WA
TECHNOLOGY	Network security and management
COMPANY	ILOG
LOCATION	Gentilly, France
TECHNOLOGY	Data management for supply-chain applications
COMPANY	Brokat Technologies
LOCATION	San Jose, CA
TECHNOLOGY	Data management for e-business

UNIVERSITY	University of Cambridge
FOUNDED	November 2000
TECHNOLOGY	Polymer microchips

PLASTIC LOGIC

STORY Tracy Staedter / PHOTOGRAPH Jonathan Olley/Network

SILICON MICROPROCESSORS PROVIDE THE brainpower for today's computers and other electronic devices. But fabricating these chips is an expensive and time-consuming process. Now a far cheaper, easier-to-manufacture integrated circuit—one made of plastic rather than silicon—is on the horizon. If these plastic-based chips prove practical, they could help give rise to inexpensive, flexible, even disposable electronic devices.

One startup looking to make that vision a reality is Plastic Logic, which sprang out of the University of Cambridge last November with physicist Richard Friend at the scientific helm. It's not the first time Friend has put polymers to work in electronic devices: in 1992 he helped launch Cambridge Display Technology to commercialize light-emitting diodes made from organic polymers for use in flat-screen displays *(see "Displaying a Winning Glow,"* TR *January/February 1999)*. Then, in 2000, Friend and his colleagues demonstrated that they could print polymer integrated circuits—the technology at the heart of Plastic Logic.

Armed with a staff of 10 and venture capital backing of more than $2.4 million from firms such as Midland, MI-based Dow Venture Capital Group and Amadeus Capital Partners of Cambridge, England, Plastic Logic intends to bring polymer transistors to market for use in products where silicon microchips are simply too expensive. Polymer-based circuitry is not nearly fast enough to run a PC, but it could be just right for use in "smart" electronic tags for tracking merchandise or in the electronics used in large flat-panel displays. And because polymer chips can be flexible, they could open the door for handheld computer gadgets that could be folded or rolled up like paper. With these and other compelling markets beckoning, says Friend, "We know why we're developing the technology. It's not a case of a technology in search of a use."

Plastic Logic is not the only company to see the potential of plastic electronics *(see table)*. What sets the Cambridge startup apart from others in the field is its manufacturing approach. Friend's team dissolves specially designed semiconducting polymers to form an "ink" and then prints the circuitry onto a flexible substrate, employing the same technology used by an ink-jet printer. It's "a very effective and elegant way of delivering polymers to the sites," says physicist Ananth Dodabalapur of Lucent Technologies' Bell Labs. "The big advantage of plastic transistors," he adds, "is that you can produce them cheaply."

Plastic Logic has yet to specify just how much cheaper than silicon they think their circuitry will be. According to CEO Stuart Evans, "Cost is difficult to pin down at this early stage." Still, he says, "It is conceivable that we could make a simple [radio-frequency identification] tag for a penny." According to Nick Darby, director of technology at Dow Venture Capital Group, Plastic Logic aims to have a working prototype of its new chip ready by the summer, and a product ready for market in three to five years.

Plastic Logic still has some hurdles to clear, though. For one thing, its manufacturing process still involves an expensive initial step borrowed from conventional chip making to prepattern the substrate so the polymer ink doesn't run. "It's not a business-model killer, but it's certainly an area that could be improved," says Kimberly Allen, director of technology and strategic research at San Jose, CA-based research firm Stanford Resources.

Meanwhile, some of the company's competitors, including Lucent, are currently working out the details of an alternative manufacturing technique that involves creating the semiconductor pattern with stamps. Eventually, says Dodabalapur, the two techniques could be used together—the stamping process might replace Plastic Logic's initial lithography step, for example.

Ultimately, says Dodabalapur, "My feeling is that the two techniques will figure among the winners." If so, Plastic Logic could soon help to create what Evans calls "a parallel universe" of cheap, smart, disposable electronic devices.

Others in Polymer Microchips

COMPANY	Lucent Technologies
LOCATION	Murray Hill, NJ
TECHNOLOGY	Printing plastic chips with stamps
COMPANY	Philips Electronics
LOCATION	Eindhoven, the Netherlands
TECHNOLOGY	Photolithography for plastic chips

Plastic Logic founder Richard Friend sees compelling markets for polymer-based microcircuitry.

UNIVERSITY	Caltech
FOUNDED	August 2000
TECHNOLOGY	Optical oscillators

OEWAVES

STORY Claire Tristram / PHOTOGRAPH OEwaves

OSCILLATORS ARE AT THE HEART OF EVERY communications device, from FM radio receivers to cell phones to sophisticated optical networking equipment. By beating out a reference signal like the ticking of a clock, they allow such gadgets to interpret and process incoming signals. But in today's oscillators the frequency of the signal is set by a vibrating quartz crystal, and quartz just isn't fast enough for the transmitters and other machines that drive optical networks. Enter OEwaves, a Pasadena, CA, startup that's using technology from Caltech to build a better, faster oscillator—one that keeps time, not with vibration, but with light.

In a conventional oscillator, an electric current causes the quartz to vibrate at a natural frequency of about five million cycles per second, or five megahertz. But optical networks currently operate at frequencies of up to 10 gigahertz—2,000 times as fast—and could eventually reach 40 gigahertz. Special equipment can multiply the natural frequency of quartz up to the rate of the network, but the process adds both cost to the system and noise to the signal. OEwaves' "opto-electronic oscillator" would solve both problems by using light to create a reference signal—tuned to any frequency required. To accomplish this, the device uses a tiny sphere of glass. Laser light beamed into the sphere is trapped, perpetually glancing off the walls; the frequency of this trapped light wave—which can be altered by adjusting the laser beam or the size of the microsphere—becomes the reference oscillation. "It's the first new approach to oscillator technology for 30 years," says OEwaves cofounder Lute Maleki. "It will reduce the cost and the complexity of the system, and it also lets the network carry more information."

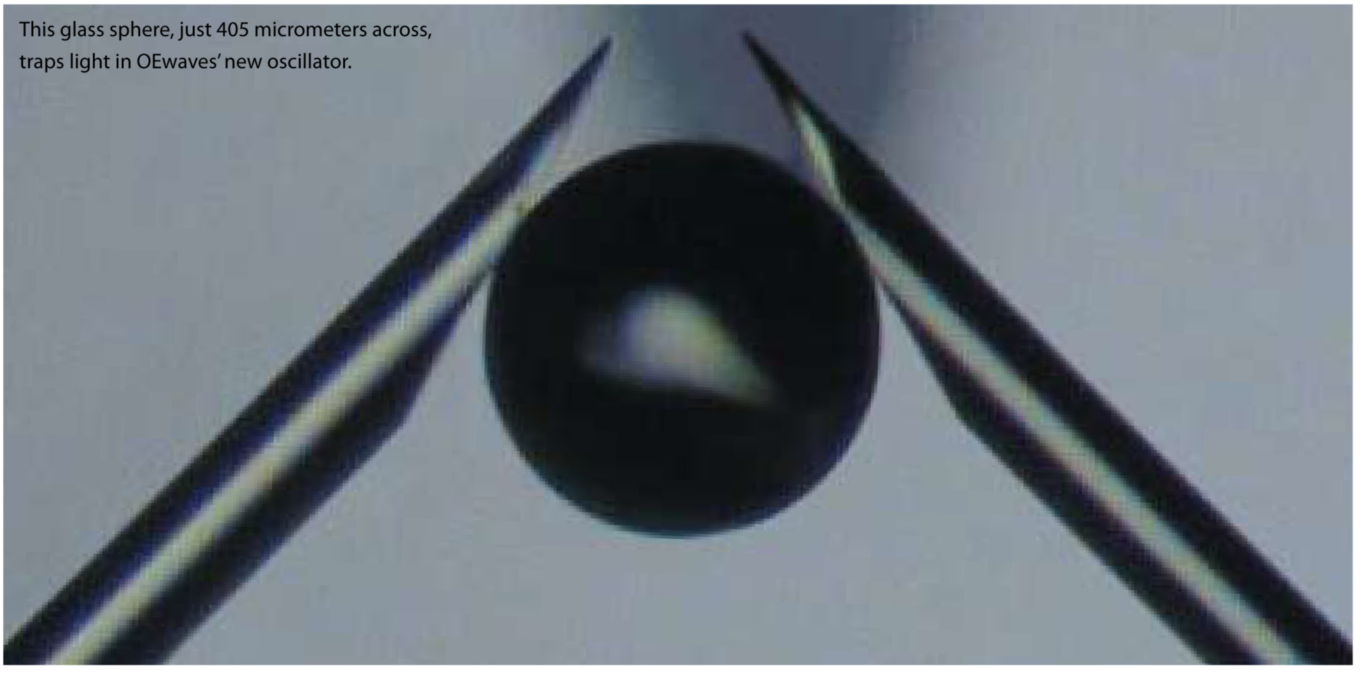
Maleki, a physicist at Caltech's Jet Propulsion Laboratory, and OEwaves cofounder Steve Yao first tried to build the optical oscillator using a length of fiber-optic cable to trap the light. The idea of using microspheres came from Vladimir Ilchenko, then at Moscow's Lebedev Institute and soon to be OEwaves' chief scientist. With CEO Julie Schoenfeld, Maleki and Yao founded OEwaves last year, raising an initial \$4.4 million. The company plans to have a working oscillator the size of a small circuit board by the first quarter of 2002. This device will be small enough to use in optical network transmitters, OEwaves' first target application.

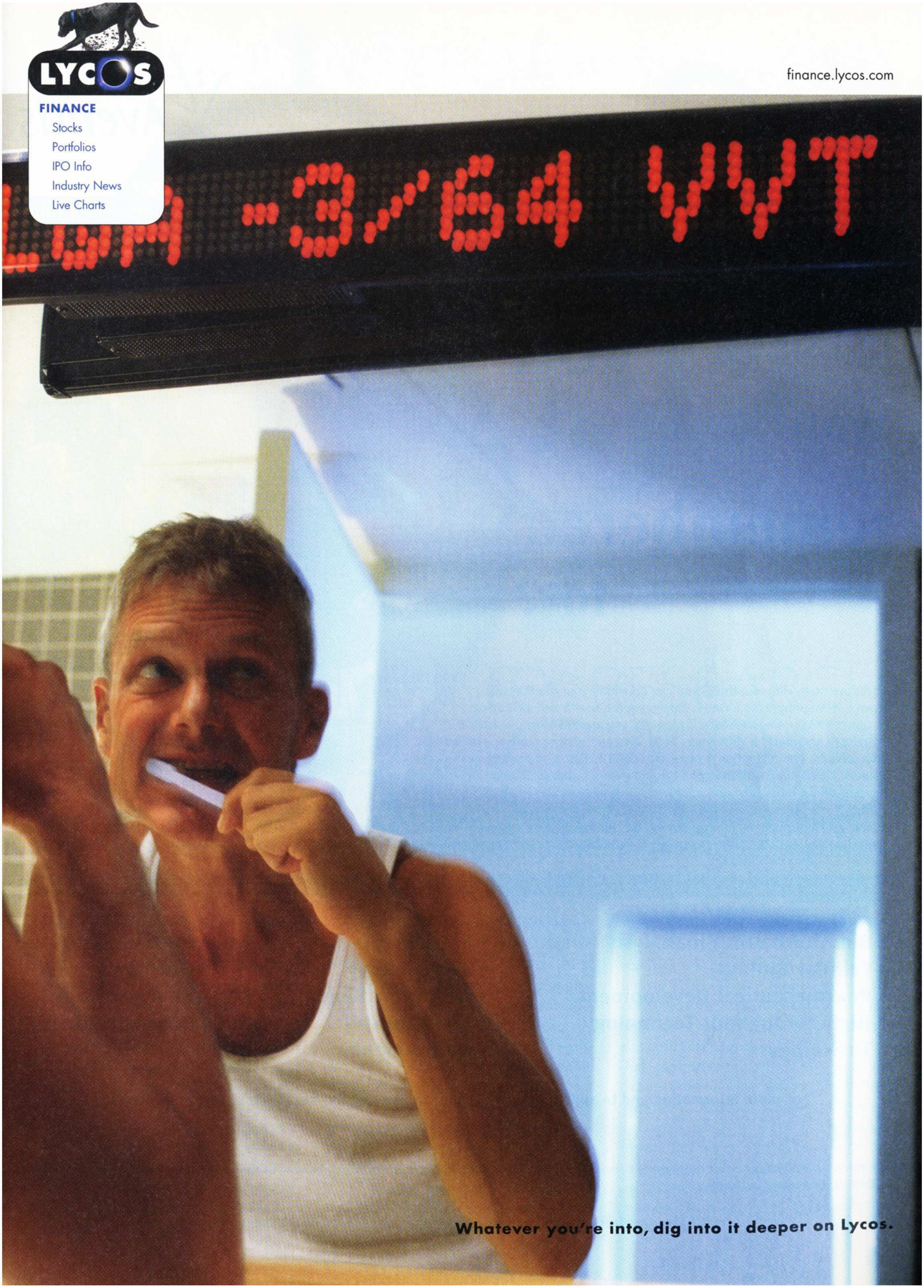
As in most new ventures, there are still many technological hurdles to overcome. A nearly identical project at the National Institute of Standards and Technology, for example, was tabled in 1999 when researchers found that minor variations in temperature would distort the signal. "As the temperature changes, it will actually change the shape of the material," says John Kitching, who worked on the oscillator project. "Then the frequency will drift around. Because of that instability, it didn't seem like it was worth pursuing."

Maleki points out that, like his own early efforts, the national lab's project used fiber-optic cable. He argues that the move to microspheres will solve the temperature problem. If OEwaves succeeds in meeting these and the other challenges it will undoubtedly face, its persistence could pay off handsomely. CEO Schoenfeld claims that a high-performance, high-frequency oscillator will have applications in markets ranging from optical networks to high-bandwidth fixed wireless networks and beyond. If she's right, OEwaves' timing may be just about perfect.

Others in Oscillators

COMPANY	Epson Electronics America
LOCATION	San Jose, CA
TECHNOLOGY	Quartz oscillators
COMPANY	NDK America
LOCATION	Fremont, CA
TECHNOLOGY	Quartz oscillators


This glass sphere, just 405 micrometers across, traps light in OEwaves' new oscillator.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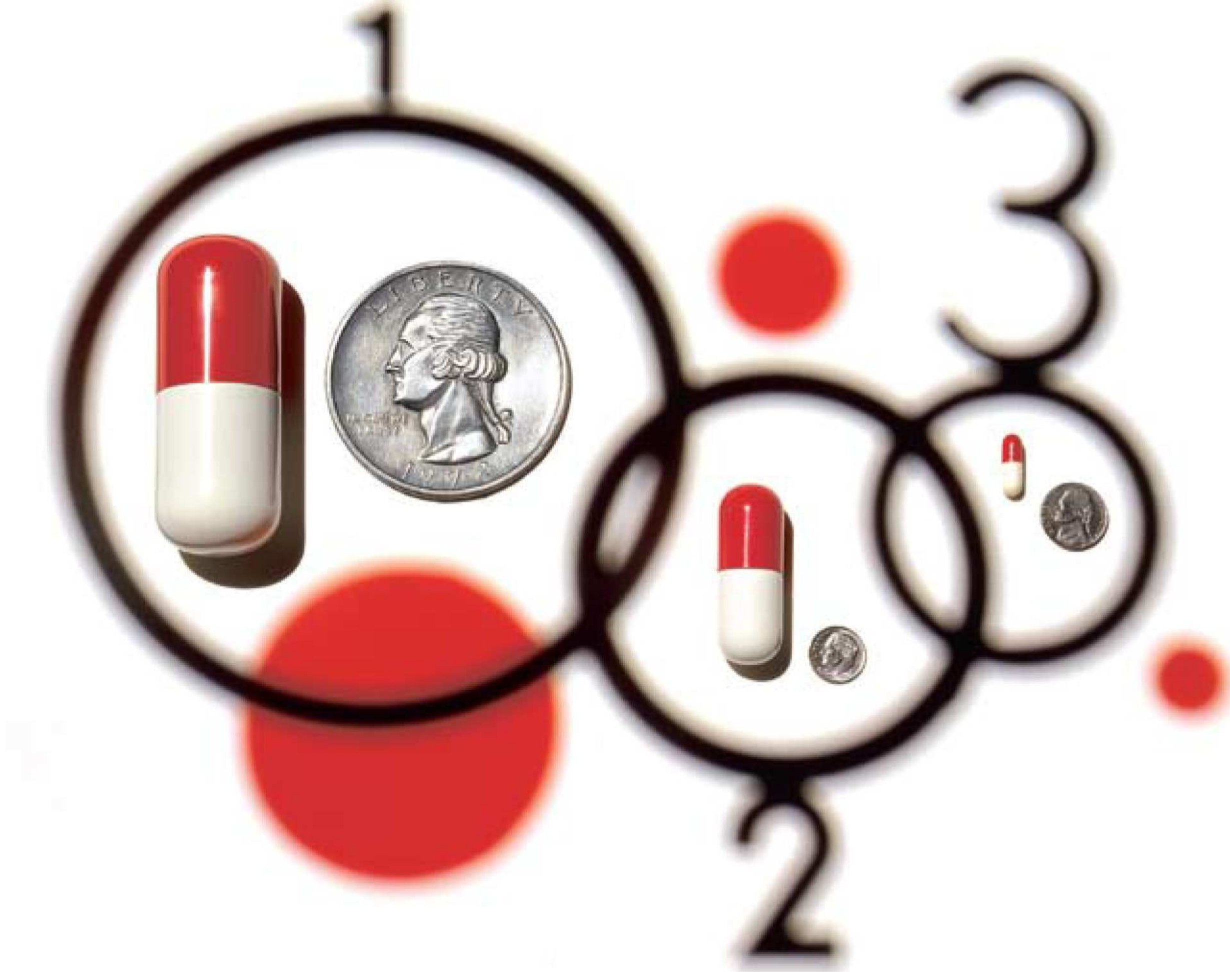


THE *TR* UNIVERSITY RESEARCH SCORECARD

Patenting and licensing at U.S. universities is going strong. Biotech in particular gets high marks.

STORY Herb Brody / PHOTOGRAPH Pierre-Yves Goavec

THE ECONOMY MIGHT BE HICCUPPING toward an uncertain fate, but one of the engines of innovation is still hitting on all cylinders. Technological advances emerging from the nation's universities are finding their way into industry at a pace that has hardly slackened in the last year. Institutions of higher learning do not cite patenting as a primary goal; top priority still goes to research and teaching. But license fees from existing patents, particularly in biotechnology, are generating hundreds of millions of dollars that universities often plow back into research.

While the business world at large is coming to its senses after the Internet hysteria of the past five years, the economics of university licensing seems to rest on more enduring verities. The first is that true technological advances are economically valuable. Another, more specific, truth is that new drugs that cure disease—or new ways to find or make these drugs—are worth a lot of money. Finally, despite the glamour of entrepreneurship, the big money for a university usually comes from patents licensed to large, established companies—not startups. With a few high-profile exceptions (most notably at MIT and Stanford, and in the University of California system), university research spawns relatively few spinoff companies.

The "Campus Patenting" chart *(p. 83)* gives a glimpse of which U.S. universities are most productive in technological invention. The data, provided exclusively to *Technology Review* by CHI Research of Haddon Heights, NJ, establish a metric (called technological strength) that quantifies the power of a school's patent portfolio. Another table *("Tech Transfer Riches," p. 82)* has a more mercenary flavor. Here we show how much money leading research universities are reaping from licenses on the patents they own; these statistics were compiled by the nonprofit Association of University Technology Managers.

For those universities interested in maximizing licensing income, the lesson plan is simple: biotech blockbusters. Chart-topping Columbia University illustrates the point. Columbia hit the jackpot with the 1983 patent by Richard Axel on a method for inserting DNA into cells—a procedure at the heart of the production of several of today's bestselling biotech drugs, including plasminogen activator, which if administered early can lessen the damage inflicted by a heart attack. Indeed, about 80 percent of Columbia's licensing revenue comes from fees paid to the university by pharmaceutical companies for three technologies, according to Scot Hamilton, senior director of Science and Technology Ventures—the university's technology transfer organization.

Biotech rules at other campuses, too. Two-thirds of the $74 million in licensing revenues flowing into the University of California system comes from patents issued to the University of California, San Francisco, School of Medicine; only about $8 million of the total arises from patents issued to the system's flagship Berkeley campus, according to William Hoskins, director of the Office of Technology Licensing at Berkeley. For third-ranked Florida State University, virtually all of its $57 million in licensing revenues comes from a patent by chemist Robert Holton on a method to produce the tumor-fighting chemical paclitaxel—marketed by Bristol-Myers Squibb as Taxol, the world's top-selling anticancer drug.

And the lion's share of Yale University's $40-plus million in licensing income comes from an anti-retroviral drug called stavudine, which is marketed under the brand name Zerit by Bristol-Myers Squibb and is one constituent of the anti-AIDS drug "cocktail." Subtract the Zerit income from its portfolio and Yale's license revenue shrinks to about $15 million, according to E. Jonathan Soderstrom, managing director of Yale's Office of Cooperative Research.

While much of the action is at the elite private schools, several public universities have made patents and technology transfer a big part of their strategies. The University of California, with its nine campuses and almost $2 billion research budget, tops the field in technological strength and comes in second only to Columbia in licensing income. And the granddaddy of university technology transfer is far from the technology-frenzied coasts. The University of Wisconsin-Madison has been licensing patents from its research since 1925, when dairy scientist Harry Steenbock discovered an irradiation process that could activate vitamin D in milk, notes Bryan Renk, director of patents and licensing at the Wisconsin Alumni Research Foundation, which handles the school's patent and license affairs.

TECH TRANSFER RICHES

INSTITUTION*	LICENSE INCOME (DOLLARSX1000)	RANK	RESEARCH EXPENDITURES (DOLLARSX1000)	LICENSE INCOME AS % OF RESEARCH EXPENDITURES	LICENSES & OPTIONS YIELDING INCOME
Columbia University	89,160	1	279,276	31.9	212
University of California system	74,133	2	1,864,901	4.0	715
Florida State University	57,313	3	132,665	43.2	14
Yale University	40,696	4	315,953	12.9	28
University of Washington	27,879	5	479,655	5.8	185
Stanford University	27,699	6	417,037	6.6	339
Michigan State University	23,712	7	207,912	11.4	48
University of Florida	21,650	8	280,408	7.7	45
University of Wisconsin-Madison	18,011	9	421,600	4.3	191
MIT	16,131	10	725,600	2.2	346
Emory University	15,258	11	205,600	7.4	35
SUNY system	13,539	12	405,238	3.3	149
Baylor College of Medicine	12,281	13	239,000	5.1	110
New York University	10,700	14	149,000	7.2	18
Johns Hopkins University	10,353	15	1,010,088	1.0	137
Harvard University	9,886	16	401,850	2.5	166
North Carolina State University	7,761	17	413,369	1.9	60
Tulane University	7,572	18	87,324	8.7	19
Washington University	7,000	19	333,196	2.1	107
Caltech	6,500	20	150,000	4.3	35
Cornell University	6,070	21	376,784	1.6	199
Carnegie Mellon University	5,892	22	167,675	3.5	51
University of Minnesota	5,662	23	417,556	1.4	153
Texas A&M University system	5,181	24	402,203	1.3	155
University of Texas Southwestern Medical Center	4,857	25	179,709	2.7	57

LICENSE INCOME: The gross license income received by the university in fiscal year 1999 minus license fees paid to other institutions. Note: Rankings within this category reflect an institution's standing among all 132 U.S. universities surveyed by the Association of University Technology Managers.

RESEARCH EXPENDITURES: Total expenditures in support of research, funded by all sources, including federal and local government, industry, foundations, voluntary health organizations and other nonprofits.

LICENSE INCOME AS PERCENTAGE OF RESEARCH EXPENDITURES: The adjusted gross license income, as described above, compared to total expenditures on research.

LICENSES & OPTIONS YIELDING INCOME: The number of licenses and options generating license income.

Data from the Association of University Technology Managers. Figures are the most recent available, from fiscal year 1999.

*individual campuses unless otherwise indicated

"Licensing is a big-hit game," says Renk, adding that Wisconsin has produced a blockbuster "just about every decade." Another Midwestern public university is rising fast in the licensing sweepstakes as well: Michigan State University. The school owes most of last year's $24 million in revenue to patents awarded to researcher Barnett Rosenberg for the anticancer drugs cisplatin and carboplatin, which have dramatically lowered the mortality rate for patients with testicular cancer and offer hope for improved treatment of ovarian and cervical cancer.

Driven in part by the prospect of dramatic licensing revenues, many universities are cultivating a culture of entrepreneurship. No wonder, then, that campus technology transfer offices are finding themselves an important stop on the tour when schools hire new research talent. "We are heavily involved in faculty recruiting," says Yale's Soderstrom. Renk says the same is becoming true at Michigan State. "New faculty are more entrepreneurial," he says. "They come interview the technology transfer officers and ask how well funded and well staffed we are." That way, prospective faculty can get a read on the level of institutional support they will receive to move their inventions out of the lab and into practical use.

A university's success in patent licensing depends on a number of factors. Columbia's Hamilton attributes his school's success in part to a creative faculty that is willing to disclose its inventions to a technology transfer office. One immutable circumstance: location. Hamilton says New York City's business-friendly environment has been a boon to spinoffs. "We're not so cloistered here—the faculty tend to be more worldly, and we find that there is less prejudice" against commercializing the fruits of research, Hamilton says.

While they work to make things as easy as possible, even the most successful patent-licensing universities view income as a happy by-product. "Our main goal is to provide a service to the faculty—to help them get their ideas out into practical use," says John Ritter, director of the Office of Technology Licensing and Intellectual Property at Princeton University. "If we get a revenue stream, that's gravy."

But it's a gravy train that more and more universities are signing up for. TR

CAMPUS PATENTING

INSTITUTION*	TECHNOLOGICAL STRENGTH 2000	RANK	1995-99†	RANK	NUMBER OF PATENTS 2000	1995-99†	CURRENT IMPACT INDEX 2000	1995-99†
University of California	437	1	346	1	460	339	0.95	1.02
MIT	179	2	179	2	121	128	1.48	1.40
Stanford University	163	3	87	4	111	71	1.47	1.23
Caltech	155	4	80	5	107	62	1.45	1.29
University of Texas	95	5	123	3	101	102	0.94	1.21
University of Washington	90	6	60	9	64	40	1.40	1.50
University of Wisconsin	68	7	76	6	65	70	1.05	1.09
Columbia University	67	8	55	11	60	42	1.12	1.32
University of Michigan	65	9	58	10	75	46	0.87	1.27
Johns Hopkins University	62	10	55	11	89	62	0.70	0.88
Carnegie Mellon University	62	10	29	26	33	17	1.88	1.67
Cornell University	57	12	64	8	53	58	1.08	1.11
Princeton University	47	13	30	24	30	21	1.58	1.44
Emory University	39	14	30	24	25	21	1.56	1.40
SUNY	38	15	46	13	55	44	0.69	1.05
Harvard University	37	16	31	23	43	41	0.86	0.76
University of Pittsburgh	36	17	26	29	40	24	0.91	1.11
University of North Carolina	35	18	40	17	41	39	0.86	1.04
Duke University	35	18	41	16	47	35	0.75	1.19
Georgia Tech	35	18	19	38	39	23	0.89	0.84
University of Florida	35	18	42	15	68	50	0.51	0.83
University of Pennsylvania	35	18	72	7	38	56	0.91	1.29
Washington University	32	23	39	18	39	35	0.82	1.13
University of Minnesota	31	24	44	14	48	40	0.64	1.09
Rutgers University	30	25	28	27	32	25	0.95	1.10
University of Illinois	30	25	17	42	28	21	1.06	0.82
University of Nebraska	29	27	20	35	27	23	1.07	0.87
Ohio State University	28	28	22	33	26	23	1.06	0.96
Yale University	26	29	19	38	33	25	0.80	0.79
North Carolina State University	26	29	34	20	28	28	0.94	1.20
Iowa State University	25	31	35	19	35	43	0.71	0.81
Baylor College of Medicine	25	31	18	40	27	19	0.92	0.98
Florida State University	24	33	23	32	14	10	1.74	2.33
Pennsylvania State University	24	33	32	21	38	27	0.63	1.16
University of South Florida	23	35	9	49	20	14	1.15	0.62
Northwestern University	23	35	18	40	19	25	1.20	0.73
Case Western University	22	37	14	44	20	14	1.11	0.99
Boston University	22	37	20	35	20	19	1.09	1.07
University of New Mexico	22	37	12	46	23	14	0.94	0.81
University of Utah	21	40	32	21	25	33	0.82	0.96
University of Tennessee	20	41	17	42	21	13	0.95	1.37
Michigan State University	20	41	24	30	42	40	0.47	0.59
Northeastern University	19	43	10	48	15	12	1.29	0.78
University of Southern California	19	43	13	45	21	15	0.91	0.87
University of Colorado	19	43	28	27	19	23	1.00	1.21
University of Massachusetts	18	46	22	33	26	27	0.70	0.83
University of Cincinnati	18	46	9	49	17	8	1.06	1.13
University of Alabama	18	46	24	30	28	25	0.63	0.98
University of Rochester	17	49	11	47	15	9	1.14	1.22
Brown University	17	49	20	35	14	12	1.22	1.72

TECHNOLOGICAL STRENGTH: The number of U.S. patents multiplied by the Current Impact Index (see below).
NUMBER OF PATENTS: The total number of U.S. patents awarded, excluding design and other special-case inventions.
CURRENT IMPACT INDEX: A measure of how frequently an institution's patents for the previous five years are cited in the current year, relative to all patents in the U.S. system. A value of 1.0 indicates average citation frequency. *Data from CHI Research*

*includes all campuses in system †annual average

Eco-logic

STOPPING OVER IN PHOENIX ON my way home to Boston a few years ago, I was treated to a rare desert sight: a storm roaring into the city.

The skies opened and rain began pouring down. Then, five minutes after the tempest started, the hotel's lawn sprinkler system came on. Pretty dumb sprinklers. In a city like Phoenix you'd think the gardeners would be running around with Dixie cups to catch every precious drop. Maybe someday the sprinklers will at least be smart enough to check the Internet for a weather report before they start watering. Or maybe they'll just ask the plants themselves.

I wish they could. When I got home to Boston, the plant in my office had withered into a desiccated, brownish heap. Unable to cry for help, incapable of reaching the keyboard to send me a desperate e-mail, neglected and ignored by the graduate students and custodians who occasionally peeked in to see if I'd returned, the poor *Spathiphyllum floribundum* (a.k.a. indestructible generic office plant) really looked like it was pushing up daisies.

Somehow, even with my black thumb, I nursed it back to health with a combination of Poland Spring water and Peter's Plant Food. But it really irked me that, in this day and age of imported strawberries and bioengineered corn, my poor office plant was forced to sit in a clay pot full of dirt with no means of support whenever I had to be away, doomed to wither and die without a plant-sitter at hand.

CLIFFORD ALEJANDRO

When I complained to the graduate students about their shameless neglect of a dying soul, their immediate response was to construct an automatic plant-caretaking system. Called Robocrop, it was designed to use a handful of sensors to monitor growth and dispense light, water and nutrients. Aside from how to prevent office ecological disasters, the questions were: What's the optimal cycling of resources to promote plant growth? Would it be better to simply leave the grow-lights on 24 hours a day, or to cycle them? Should the light sources move (like the sun) or just remain overhead? Could a time-lapse camera watch and measure the plant's response to various stimuli? Does playing Mozart really grow the biggest tomatoes, or could the students systematically put Napster to work to hone in on the absolute best music for tomato production?

Often the cycles of a busy life make it impossible to properly care for plants. And just as often, your own instincts about when to water or supply plant food may not be in tune with the plant's true needs. So perhaps a little Internet-controlled herbal garden, with a sensor network and computer-driven drip-watering and misting system could keep a supply of basil and other cooking plants fresh and healthy and at hand. I often think that such a system would make a nice addition to, say, Hewlett-Packard's catalogue of scanners and printers. Maybe someday little packets of seeds will be hanging next to the ink-jet cartridges at CompUSA.

There is a real opportunity and need to better connect with the lives of plants, and it isn't only about keeping your office lily alive, or about applying "green" techniques to your lawn. There are larger ecosystem issues that need a more vigorous systems approach. For example, climate change and the coevo-

lution of various species are clearly critical issues, but in some respects we know about as much about those issues as we do about our own backyards, which is to say, not much.

A few years ago, MIT students Matt Reynolds and Rich Fletcher were inspired by an expedition to Mount Everest to construct a device to measure the weather there. They built a bomb-proof (and Everest-proof) weather sensor in a plastic pipe and bolted it to the mountain, where it recorded the data for nearly a year and transmitted the results via satellite onto the Internet. Conveniently, National Oceanic and Atmospheric Administration satellites swing overhead about ten times a day. It's a store-and-forward system: the probe tosses up a 32-byte payload (enough for a couple hours of weather samples), and that packet blinks off the satellite and onto the Internet. At base camp, support teams can radio the climbers at higher-elevation camps ("It's calm and sunny on the summit—now go for it!").

Even the Weather Channel got interested enough to fund a few such probes ("It's 79 degrees in Boston, partly cloudy, and…this just in, folks: the live weather from Mount Everest is…"). This work is still at the stage in which computer engineers are probably learning more than ecoscientists, but it's a valuable start.

Climate change and the coevolution of species are critical issues for understanding our planet; but we know as much about these areas as we do about our own backyards, which is to say, not much.

More recently, a team of ecologists from the University of Hawaii was introduced to engineers at MIT. The group's tactical mission: gather information about the extremely rare *Silene hawaiiensis*, a plant that lives in the southwest rift zone of the Halemaumau crater amid the volcanoes on the big island of Hawaii.

Island ecosystems are known for the starkly drawn lines between species. This is why Darwin discovered a living laboratory in the Galápagos, and why Alfred Russel Wallace was bowled over by the Indonesian archipelago. The island of Hawaii is home to a number of intriguing species, including curiosities like thornless berries and nettleless nettles: plants that enjoyed the paradise so much that they relaxed their natural defenses. In recent decades, though, Hawaii has become an ecological battlefield as alien species invade and disrupt the old balance.

Fieldwork for this project began on the northeast shore of Hawaii, in Hilo, the United States' rainiest city. But a 50-kilometer drive southwest to Hawaii Volcanoes National Park brings you into a desert microclimate. Going from rain forest to desert in the space of a few kilometers makes this one of the world's more sharply delineated climate zones.

There, around the ash-crusted rim of the massive Kilauea caldera, a few hundred scrappy little *Silene* plants are growing. They're an endemic species, and not much is known about them. We don't know how they pollinate, and we don't really have a handle on the very particular climate in the area in which they're growing.

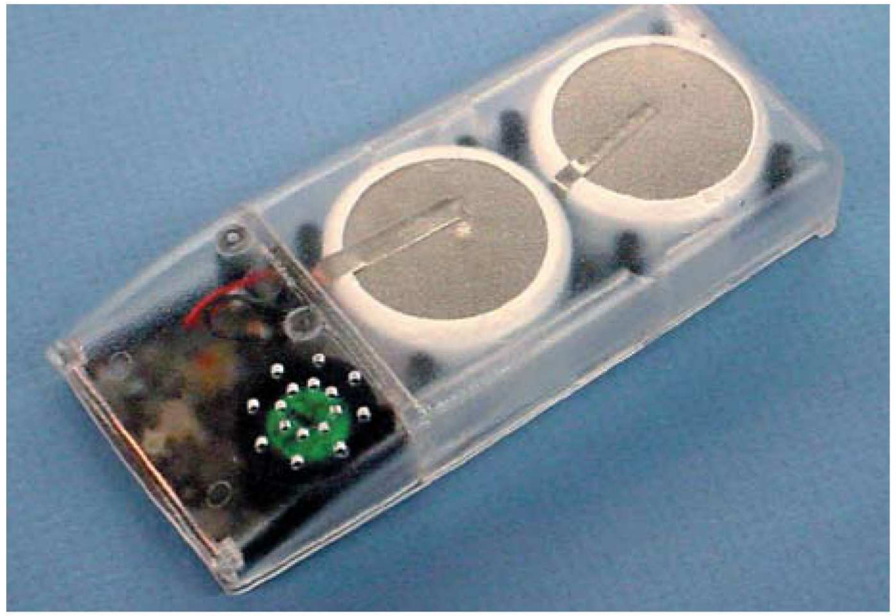
Not too far from the *Silene*, you'll find another extremely rare plant, the *Portulaca sclerocarpa*. There are perhaps only a hundred of these on earth, and they grow in one tiny patch in a place called Puhimau. What's especially interesting about their little grubstake is that if you walk a few hundred meters away from the *Portulaca* and stick a thermometer five or six centimeters into the ground, the temperature reads 85 °C. And when you look around, you see the charred remains of a forest. What's happening is that an underground lava flow is heating the soil, killing the plants above, and it could easily wipe out the precarious *Portulaca* patch.

These sorts of phenomena require time-lapse logic, and time-lapse thinking. Because we're in a wilderness within a national park, any instrumentation needs to be autonomous and wireless and very unobtrusive. So the combined MIT and Hawaiian teams came up with a novel approach. Students Andy Wheeler, Roshan Baliga, Ben Brown and Paul Pham built a tiny computerized climate sensor to measure light, temperature, humidity and wind speed. The nodes look like eight-by-eight-by-three-centimeter blocks, and they have radio links designed to self-aggregate into a wireless network. By sprinkling enough of these in an area, you can blanket a critical piece of territory with all the sensing required to form a much more detailed picture of what's going on ecologically. And with clever camouflage that looks like logs and rocks, the sensors blend into the ecosystem.

Biology professor Mike Huddleston, associate professor of botany Kim Bridges, and their team at the University of Hawaii built some remarkable faux rocks and logs to hold the assorted electronics. In principle, a scientist simply walks out from the observatory with a bag of these high-tech rocks and drops one every 15 meters or so to form a daisy chain that leads out to the nearby *Silene* patch. The rocks look uncannily like the local chunks of tephra that are blasted out of volcanoes, and that's how this first tephranet got its name. If it works, it should run for several months, producing the first intimate data snapshot of this extraordinary ecosystem.

Lush plants are a healthy part of life. Whether it's a happy plant on the office window ledge, or a deeper understanding of how the last few members of a species are clinging to life, directing new capillary sensor networks into ecosystems can bring us real insight into problems that matter. Maybe the idea of a joint venture between Hewlett- Packard and seed giant Burpee seems a little far-fetched. But when I saw MIT student Andy Wheeler with his laptop walk over to an unsuspecting pumice rock and log into it via the tephranet radio, it was as if he'd opened a door to a new world. TR

VISUALIZE



COURTESY OF AER ENERGY RESOURCES

Zinc-Air Batteries

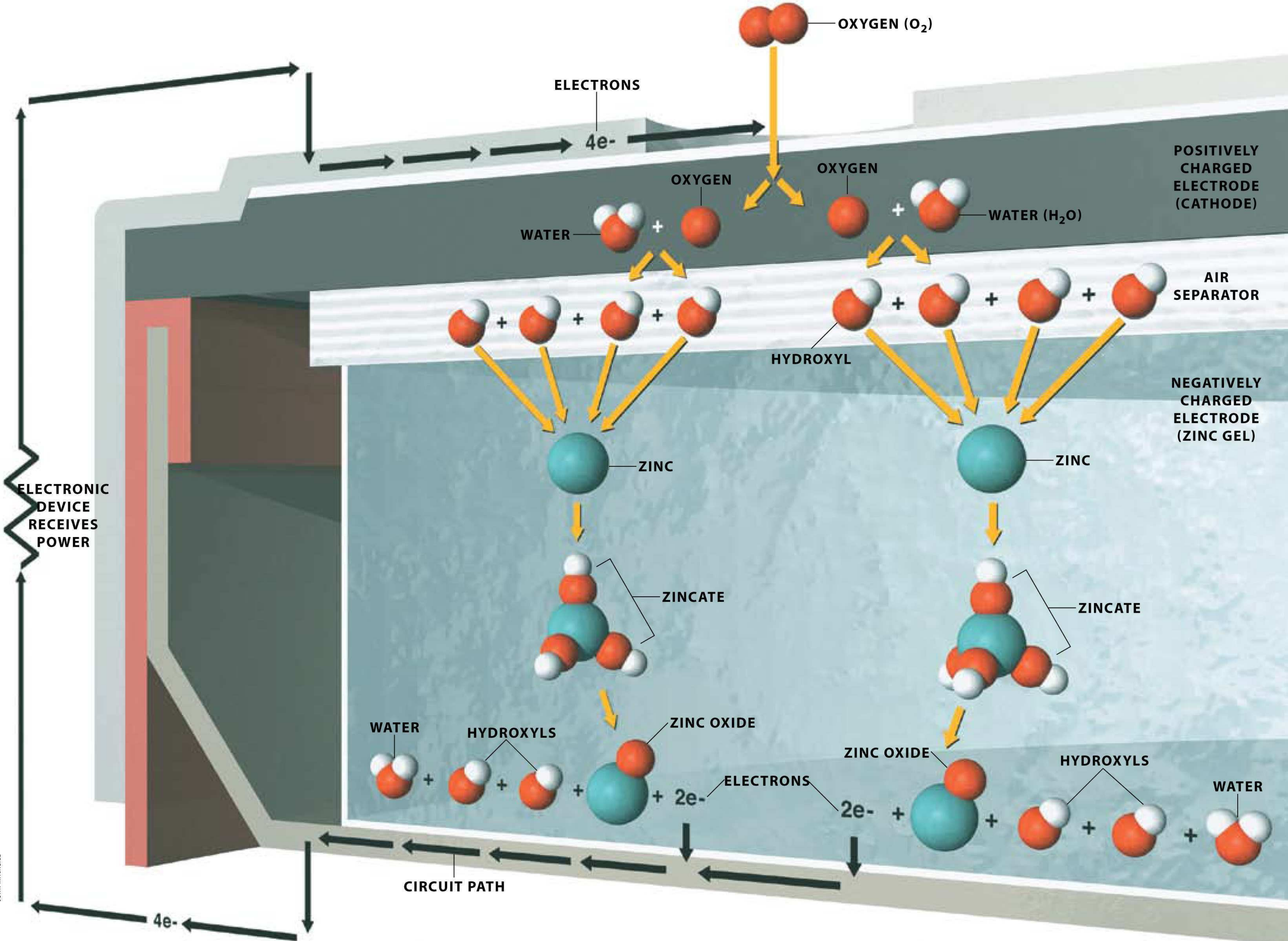
Air-breathing batteries power portable electronics

IN A WORLD GONE PORTABLE, BATTERIES ARE KEY. WITHOUT THOSE unassuming little power supplies to run our laptops, cell phones and personal digital assistants, we might as well return to the days of paper and pigeons. For as much as batteries offer, though, they still annoy us with their frequent need for recharging or replacement altogether. Lately, the zinc-air battery has been turning up as a new choice of power for handheld electronics, providing up to three times the energy of common alkaline batteries in a more compact package.

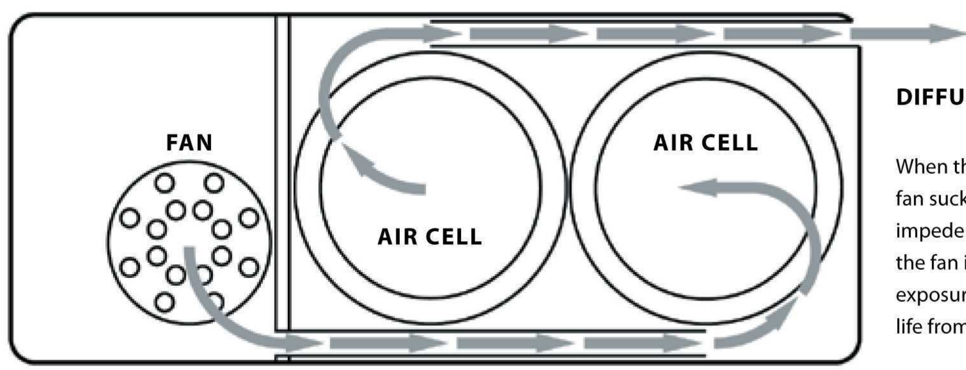
Zinc-air cells work like conventional batteries in that they generate electrical power from chemical reactions. But instead of packing the necessary ingredients inside the cell, zinc-air batteries get one of their main reactants—oxygen—from the outside air. Oxygen molecules enter the cell through tiny holes in the top and then come into contact with a positively charged electrode (cathode) made of porous carbon. Water and other molecules already present in the pores of the electrode react with the oxygen to produce hydroxyl. These molecules, and other preexisting hydroxyls, migrate through an air separator to a negatively charged electrode (anode) that consists of a zinc gel. The hydroxyls bond to a zinc molecule to form zincate, which immediately splits into two hydroxyls, a water molecule and zinc oxide, and releases two electrons that travel through a circuit to power a device—usually a cell phone or hearing aid.

Using a reactant from the air saves on space, reducing the size and weight of the battery. And unlike some batteries used in wireless devices, zinc-air cells contain no toxic compounds and are neither highly reactive nor flammable. In fact, they can be recycled, safely disposed of, or in some cases, recharged with new zinc. Their only downside is that constant contact with ambient air can either dry up the zinc gel or, if conditions are too humid, flood it with water vapor. Both render the battery less potent. AER Energy Resources of Smyrna, GA, has found a way to diffuse the air *(bottom inset)*. And another company, Electric Fuel, is developing zinc-air battery technology for automobiles. Instead of sucking gas, our cars could one day be breathing air. TR

See animated versions of Visualize at www.technologyreview.com/visualize



JOHN MACNEILL



DIFFUSION AIR MANAGEMENT SYSTEM

When the battery needs to deliver power, a tiny fan sucks in air through long narrow tubes that impede air molecules from moving freely when the fan is turned off. Limiting the zinc gel's exposure to ambient air increases the cell's shelf life from three weeks to three months.

Good News, Bad News

THIS IS A GOLDEN AGE FOR news junkies. You can access hundreds of newspapers—not to mention magazines, e-zines and a plethora of other sources—on the Web for free. Most mornings, I download the *Washington Post* for its political coverage. When reading one newspaper isn't enough, I read the *San Jose Mercury News* for its technology reporting, the *New York Times* for its international coverage and the *Atlanta Journal-Constitution* to reclaim my southern roots. Though I reside in Massachusetts, I almost never read the *Boston Globe*. Not much of interest to me there.

I read these various papers in search of local differences and regional perspectives. But will these viewpoints prevail? We may be watching America's strong tradition of city newspapers gasping in the snare of the Web's more geographically dispersed communications. Local papers face stiff competition on the Internet, vying for the attention of not only news enthusiasts but sports fans and movie buffs already gleaning their information from the likes of ESPN and *Entertainment Weekly*. The American news media are facing a moment of transition, an unavoidable evolution. And though they desperately try to define a niche for themselves, many will find their days numbered.

America's newspapers have their roots in our country's ideologies and geography. While other nations are dominated by competing national papers, America's expansiveness made national papers impractical. A change occurred in the mid-19th century, with the introduction of the telegraph. It enabled the rapid distribution of news, and thereby entailed a more objective mode of writing, so that stories could be reproduced without regard to local context.

The Web is completing the task the telegraph began. Today, much national news comes over the Internet, resulting in less local inflection of the news. Americans now get more of their news from national sources such as the Associated Press than from local media outlets. With the refocus on national rather than local news, regional papers have slashed their staffs or closed their doors.

Perhaps the big city newspaper has simply outlived its usefulness. The average American moves 11 times over the course of a lifetime, often crossing regions in search of employment opportunities. Why read a city paper when you have so little long-term investment in local communities?

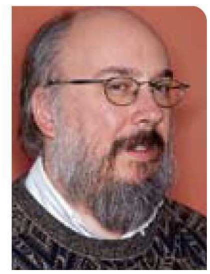
The economic base for local newspapers is also withering. Historically, local department stores were the biggest purchasers of advertising space, but national franchises are more apt to benefit from buying ad space in national publications. Classified advertising is migrating toward the Web, since it allows sellers to place their goods before the largest possible buying public.

Defenders of regional newspapers argue that they are our only hope against the homogenization of information and the concentration of media ownership. Yet in many American cities, rival papers have folded, leaving only one daily paper—and increasingly, those papers are controlled by national syndicates.

To survive national competition, daily papers are going to have to rethink how they do their business. New publications defined through affinity or demographic groups will arise, built around "virtual communities." The African-American and immigrant press has long followed this pattern: for example, half the readers of the black-owned *Chicago Defender* were outside of Chicago. On the Web, new kinds of niche publications will become more common.

Other papers may exploit regional advantages through specialization. The *Boston Globe* could expand its coverage of higher education, the *Los Angeles Times* its treatment of entertainment and the *San Jose Mercury News* its reporting of high-tech industries. Much as school districts create magnet programs to offer

Big city papers are gasping in the snare of the Web. Many are finding their days numbered as Internet news junkies cherry pick from multiple sites.



educational opportunities that could not be provided within any one local school, newspapers might develop magnet sections that command the interest of anyone who wants to be in the know on particular topics.

These trends may well improve the overall quality of American journalism, offering deeper coverage of specific sectors. Readers will be able to cherry pick the most relevant or interesting information from multiple papers. I already do it every morning, but my choices could become better. Some Web-based publications, referred to as "para-sites," filter the news for their niche readerships, linking to relevant stories drawn from many different publications. Slashdot, which targets young technically aware readers, is a good example.

Let us now pause to mourn the passing of the city newspaper, once the voice and embodiment of our regional differences. And let us now hope that the various new forms of journalism that stand poised to take its place will more fully reflect our modern lifestyles and the diversity of our contemporary culture.

ESSAY | DAVID GOODSTEIN

Science Education Paradox

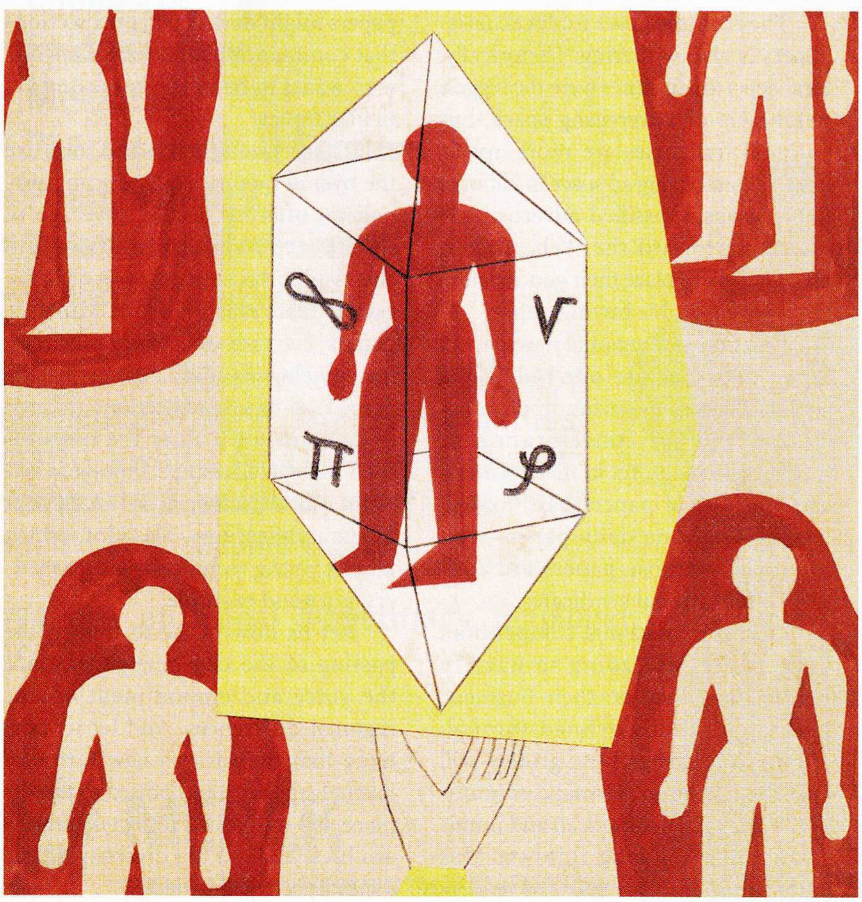
How can the same system produce scientific elites and illiterates?

THE UNITED STATES BY ANY conceivable measure has the finest scientists in the world. But the rest of the population, by any rational standard, is abysmally ignorant of science, mathematics and all things technical. That is the paradox of scientific elites and scientific illiterates: how can the same system of education that produced all those brilliant scientists also have produced all that ignorance?

The situation is not merely paradoxical; it's downright perilous. We face an era that promises ever accelerating technological change in every aspect of our lives, while at the same time the very survival of our civilization may depend on our ability to make wise decisions about how to manage our resources, our climate and our conflicts. In the next century, we will need to be able to deal confidently with technical issues, and a responsible electorate will need to have some reasonable mastery of how the world works.

In these circumstances, an undergraduate major in science should be the best possible preparation for any serious profession. Or, put another way, the science major today should be what classical Greek and Latin were in the 19th century, and the liberal-arts major was in the 20th: the union card required to enter the professional world. Unfortunately, the science education we have in place to provide this union card could not be less suited to the task.

Science education in the United States today exists as a kind of mining and sorting operation, in which we, the existing scientists, cull through what comes our way, searching for diamonds in the rough that can be cleaned and cut and polished into glittering gems just like us. The rest are cast on the slag heap, left to fend for themselves with no basic understanding of the sciences. The paradox of elites and illiterates exists because our system of science education is designed to produce that result.



PHILIPPE WEISBECKER

The problem starts in grade school, where few children ever come into personal contact with a scientifically trained person—including, unfortunately, their teachers. In most of the United States the only way you can graduate from college without taking a single science course is to major in elementary education. And, it is said, many people major in elementary education for precisely that reason. Our elementary school teachers are therefore not only ignorant of science; they are hostile to science. That hostility must, inevitably, rub off on the young people they teach.

A few years ago, I was on a committee to look into how well the "breadth" requirement—that all students take at least one course in science—was working at one University of California campus. We found that, of those students not majoring in a technical subject, 90 percent were satisfying the breadth requirement by taking a single biology course known informally among the students as "Human Sexuality." Now, I don't for an instant doubt that it was a useful and interesting course. It may even have tempted students to do hands-on experiments on their own time (a result we seldom achieve in physics). But I don't think it constitutes a sufficient education in science for university graduates at the dawn of the 21st century.

I also know a bit about what goes on at the secondary level because in

the 1980s I made an educational TV series, *The Mechanical Universe*, that's still widely used in U.S. colleges and high schools. There are about 24,000 high schools in the United States. Nobody knows how many trained high school physics teachers there are (with, say, the equivalent of an undergraduate major in the subject) but certainly there are no more than a few thousand. I made *The Mechanical Universe* primarily for the "crossover" teachers, those who teach physics even though they weren't trained for it. It's a source of great satisfaction that hundreds of teachers have thanked me for making it possible for them to have successful careers. But guess what? They tell me *their* greatest satisfaction is not in preparing the rest of their students to thrive in an increasingly technical world, but in finding those diamonds in the rough that can be sent on to college to be cut and polished into real physicists.

But nowhere is the problem more vivid than in graduate school. Graduate students are the elect, those selected to go on to the final stage of the mining and sorting operation. The average professor in a research university turns out about 15 PhDs in the course of a career. While the problem of science education is often framed in terms of a perceived lack of PhDs—too few elites to fuel our scientific and technological progress in the future—it's clear we actually have a process in place equipped to multiply our kind 15 times over with each succeeding generation. What's lacking is a means to provide the rest of our population with even the most basic understanding of science in an increasingly science-driven world.

My friends from around the country tell me that the number of undergraduate physics majors is at its lowest point since Sputnik, nearly 50 years ago. That's not surprising. The undergraduate major in physics is largely regarded as preparation for graduate school, and the academic job market is still saturated from the influx of baby boomer PhDs in the 1970s, dissuading potential new candidates from pursuing an undergraduate science degree. Those without an interest in an academic profession don't see a degree in physics as relevant. Thus, far from being the liberal-arts major of the 21st century, the undergraduate science major has become an endangered species.

Is there any conceivable remedy? Can we imagine a world in which we do better than turn out a handful of PhDs, many of whom will wind up with little but frustration to show for all their hard work, while the rest of the young people who graduate from college are unprepared to cope with a society shaped largely by science and technology? Of course, it would help if those of us who teach science in college would change our own attitudes and devise more inviting ways of presenting our subjects. But even if we could do that it would barely make a dent in the problem. By the time the kids get to us, they are already lost to science.

But imagine a world in which teaching in high school is such an attractive profession that it would be worth the trouble of a doctoral level education to get the job. For that to happen, we would have to pay teachers more, at least as much as what graduating doctoral students get. And they should be paid more. But that's not the whole answer. Just as important, schools would have to learn to treat these teachers with professional respect, and society would have to afford them the honor and admiration that professionals expect. This is not unthinkable. Something like it was true in much of Europe before World War II. But it is very far from true in today's United States.

Much more is needed, of course. The revolution would have to extend right down to the first grade. Teachers would have to be literate in science, and kids would have to find learning science as cool as following the fortunes of rock groups. That's an awful lot to ask for. But then again, only our future depends on it. TR

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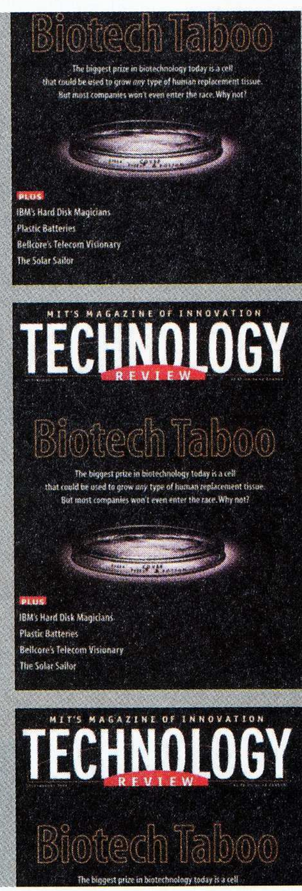

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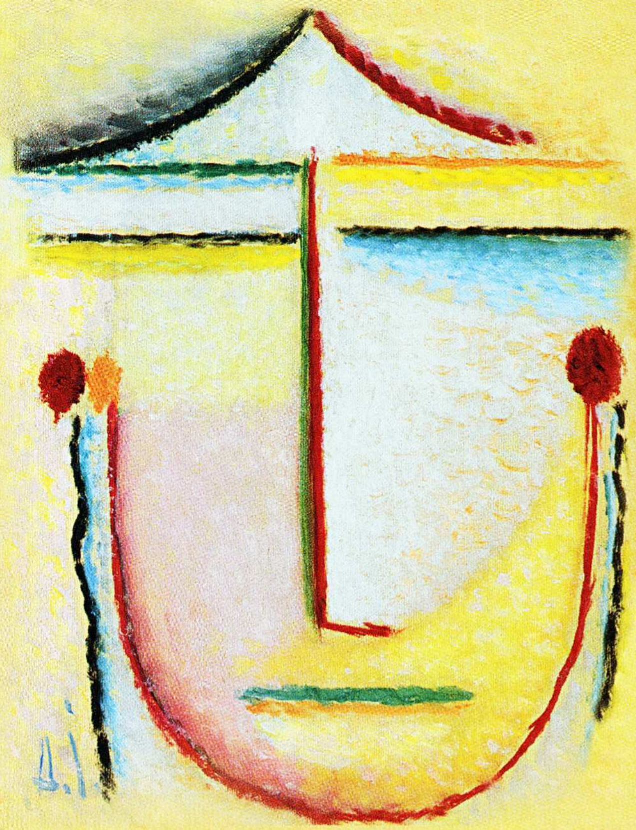

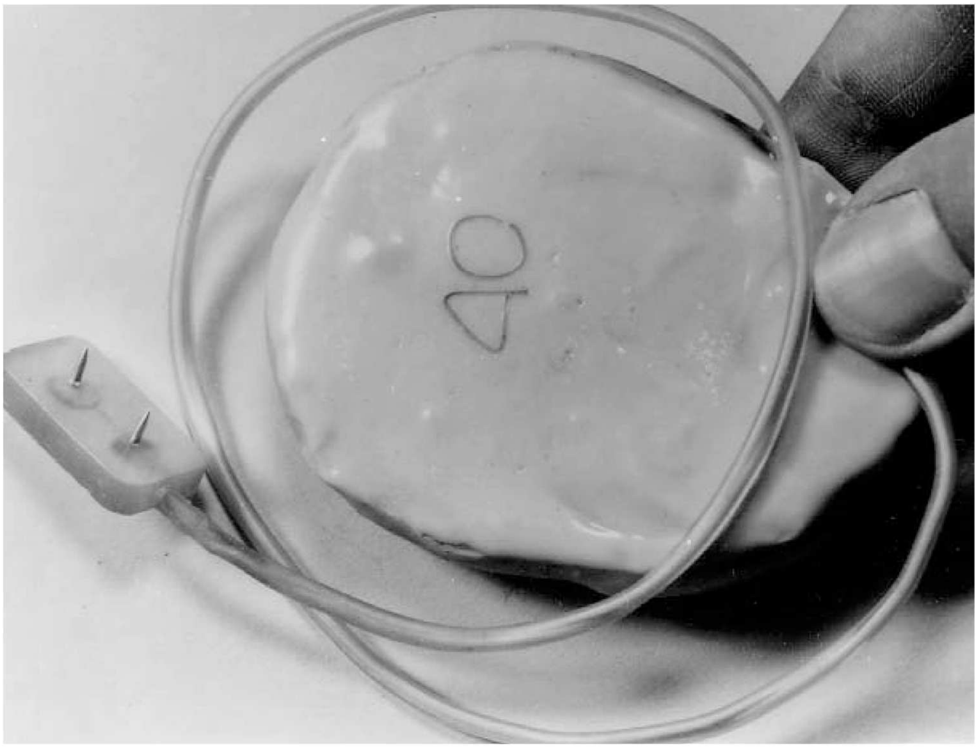

COURTESY OF PROMETHEUS BOOKS

Setting the Pace

Wilson Greatbatch's mistake sparked the medical-electronics industry

EVERY YEAR, MORE THAN 250,000 people get a new lease on life when pacemakers begin tapping out a steady rhythm for their irregularly beating hearts. Doctors had long been searching for a way to help such patients when the implantable cardiac pacemaker was marketed in 1961; a simple mistake pointed the way.

In 1956, a University of Buffalo electrical engineer named Wilson Greatbatch was using some early silicon transistors to build a circuit to help the nearby Chronic Disease Research Institute record fast heart sounds. He accidentally installed the wrong resistor into the circuit, and it started to pulse in a recognizable "lub-dub" rhythm. Greatbatch was already aware of a problem called "heart block," in which the organ's natural electrical impulses don't travel properly through the tissue; he quickly realized that this circuit was exactly what was needed to steady these sick hearts.

At the time, clunky external cardiac pacemakers existed, but they plugged into wall outlets and had external electrodes that burned the skin. Greatbatch's circuit formed the basis for a painless, implantable device. But he found little enthusiasm for his invention until April 1958, when he met William Chardack, chief of surgery at the Buffalo Veterans Administration Hospital, who immediately saw the pacemaker's potential. Three weeks later, on May 7, Chardack and Greatbatch successfully implanted their first model in a dog. However, bodily fluids seeped past the electrical tape used to seal the gadget, shorting it out after only four hours.

Greatbatch recast the pacemakers in epoxy blocks, and within a year prototypes lasted four months. The team began looking for its first human patient—but Greatbatch's employer, Taber Instrument, did not want to take on the potential legal liability of the unproven device. So armed with $2,000, he set out on his own. He hand made 50 pacemakers in a barn workshop, and in April 1960, Chardack implanted the first of 10, seen above, into patients. That year, Minneapolis-based medical electronics firm Medtronic licensed Greatbatch's invention; it remains the top manufacturer of cardiac pacemakers.

Greatbatch continued to improve his creation's design and soon developed a corrosion-free lithium battery, helping extend the life of pacemakers from two years to 10. Today, Wilson Greatbatch Technologies of Clarence, NY, is the world's largest manufacturer of implantable lithium batteries. TR

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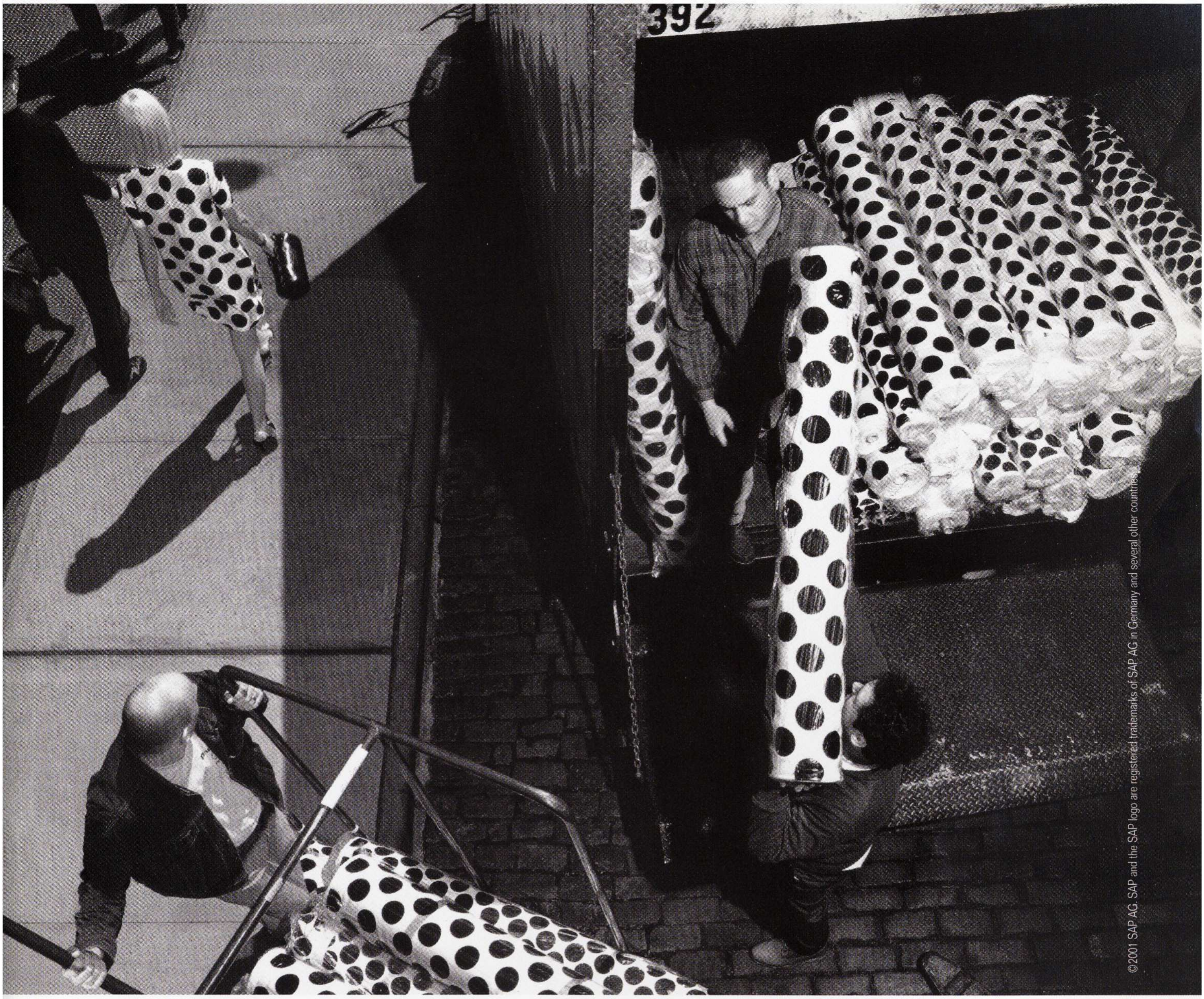

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